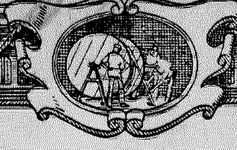
(Please circulate to your Staff.) Mr. L. C. Pocock. N.S.



ELECTRICAL COMMUNICATION

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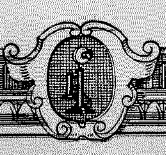

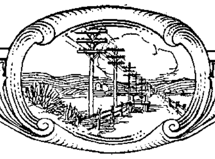

ELECTRICAL COMMUNICATION

A Journal of Progress in the Telephone, Telegraph and Radio Art

H. T. Kohlhaas, Editor

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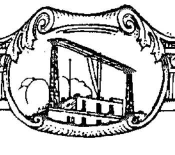

PLANT OF LE MATÉRIEL TÉLÉPHONIQUE,
PARIS, FRANCE, FOR THE MANUFACTURE OF
COMMUNICATION APPARATUS AND EQUIPMENT

Extension of Sottens Broadcasting Station to 100 KW

By E. METZLER, Dipl. Ing.,
Engineer in Charge of Swiss Telegraph Administration's Radio Division,

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Standard Telephones and Cables, Limited, London, England

WHEN the Swiss T.T. Administration took in hand the task of providing a comprehensive broadcasting scheme to cover the whole country, plans were based on a regional scheme involving among others a high power station at Sottens to serve the French-speaking zone. This station was opened in 1931 with an initial power of 25 kW., and provision was made for a future increase in power should circumstances make this desirable.

In 1935 the decision was taken to raise the power to 100 kW. and, at the same time, to incorporate the latest methods in broadcasting technique. An order for this conversion was placed in January, 1935 with the Bell Telephone Manufacturing Company of Berne.

Ten months later, in November 1935, cutover of the entire extension was effected, the work of installation, adjustment, and testing having been completed without interruption to the broadcasting service.

The changes necessitated by the fourfold increase in power, accompanied by modernisation throughout, are such that, for descriptive purposes, it is preferable to consider the equipment as entirely new rather than as an extended installation.

A general idea of the layout can be obtained from Fig. 1. It shows a plan view of the ground floor on which is installed the transmitter proper and all power supplies except the high voltage rectifier which, together with the smoothing system and the valve water cooling plant, is accommodated in the basement of the station.

The main features which characterise the design of the equipment may be summarised as follows:

(*A*) The equipment is systematically section-

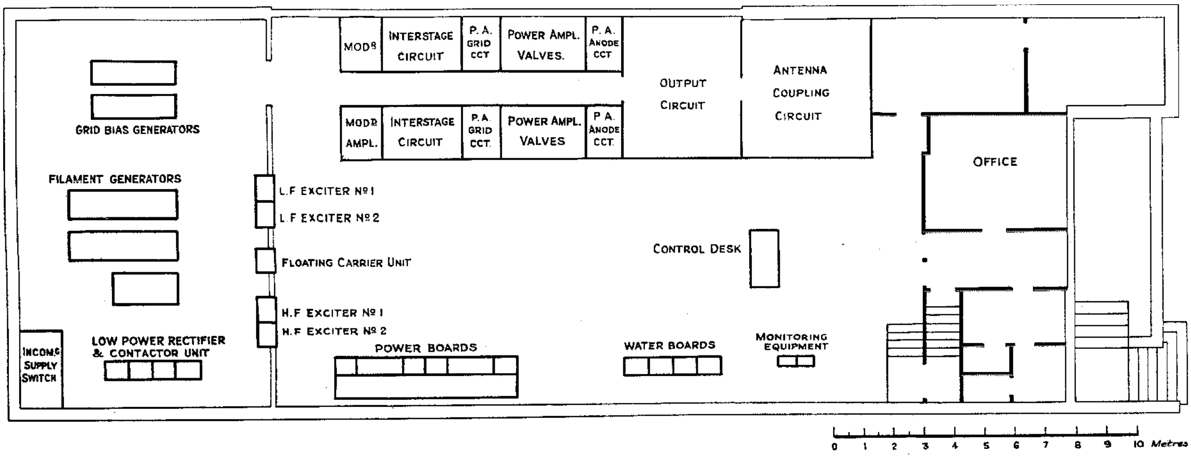


Fig. 1—Plan of Ground Floor Layout of Sottens Extension, Showing Transmitter Proper, Power Control Board, Water Control Board, Control Desk, Monitoring (Testing) Rack, and Machines. In the Basement are Installed the 18,000 Volt Rectifier, H.T. Smoothing Systems, and Water Cooling Systems.

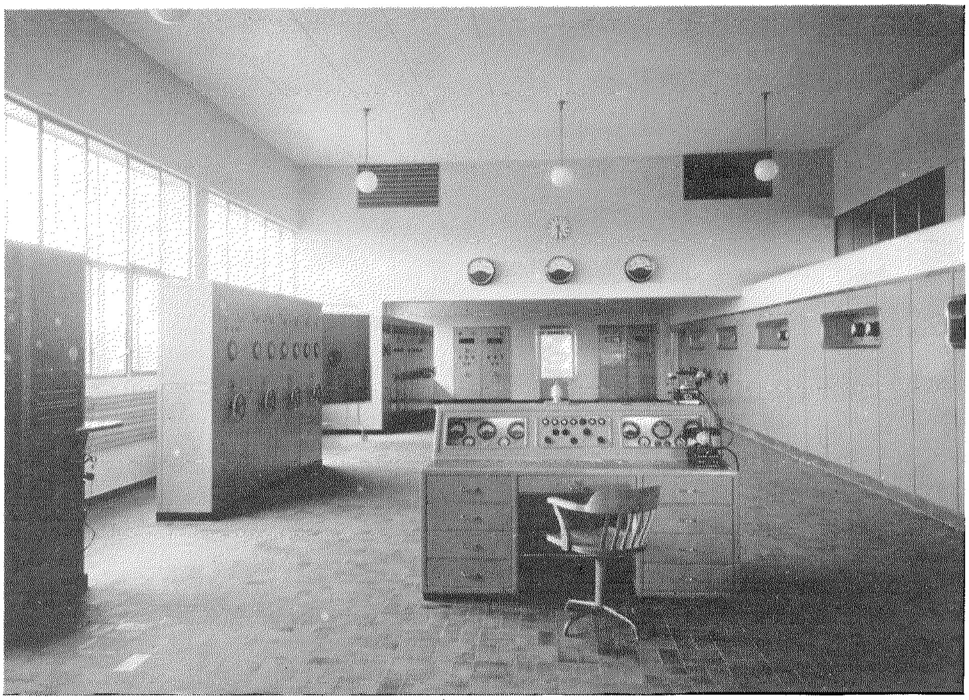


Fig. 2—Transmitter Hall.

alised according to the functions of the component parts.

(*B*) The low power "exciter" stages, both high frequency and low frequency, are in the form of self-contained units, supplied in duplicate, with means for quick changeover. With the exception of filament heating, all power supplies for these units are obtained from metal rectifiers.

(*C*) The high power stages, including the modulator, modulated amplifier, power amplifier, and output circuits are built in the cubicle type of construction which gives exceptional freedom of access.

(*D*) Spare water cooled valves are mounted in each position, and mechanism is provided for quickly changing over the electrical supplies and the water.

(*E*) Screen grid valves are used in all low power radio frequency stages, resulting in simplification of circuit adjustment.

(*F*) All voice frequency amplifiers are in push-pull, giving improved transmission quality.

(*G*) Extremely high R.F. harmonic suppression is obtained by means of special filter circuits in the output stages.

(*H*) The system can be converted from "stable carrier" to "floating carrier" whenever desired, even during a programme item, by means of a floating carrier input equipment.

(*I*) No line amplifier is required, as the L.F. exciters can be fully driven with a very low input.

(*J*) Rotating machines are used only for filament and grid bias supplies and water cooling pumps and fans.

(*K*) Complete water flow, temperature, and pressure measuring equipment is provided, concentrated on a "water control board."

(*L*) Use of perishable materials such as rubber and wood has been avoided.

(*M*) The protective system is mechanical with additional protection by an electrical interlock system.

(*N*) Provision is made for monitoring and measuring noise level and distortion at a number of points in the equipment, and a fully equipped test position is provided whereby all the transmission characteristics—frequency response, harmonic content, etc.—can be measured in a few minutes as a daily routine operation. This new scheme has proved to be very useful and will soon be adopted in all the Swiss Broadcasting Stations.

(*O*) All rotating machinery is provided in duplicate with means for quick changeover.

The transmitter proper, manufactured by Standard Telephones and Cables, Limited, London, is installed in the main hall of the station (Fig. 2). It comprises the following principal assemblies:

(*a*) Radio frequency exciter unit (Fig. 3), crystal controlled, and delivering an output of 500 watts to the modulated amplifier. This exciter is of cabinet construction with dimensions approximately 2.2 m. ×0.82 m.×0.57 m. All apparatus and valves are completely enclosed but easy access can be obtained through a door in the back of the cabinet opened by means of a key which forms part of the interlock system. The crystal is contained in a double-chamber oven, each chamber having its own temperature control system consisting of a mercury in glass thermometer acting on the grid of a mercury vapour relay, the plate circuit of which includes the chamber heating element. By means of a small variable condenser it is possible to vary the frequency of the crystal controlled system over a range of ±20 parts in one million. If, under special circumstances, it is necessary to make a large change in the frequency, the first stage of the exciter may be used as a self oscillator. The unit includes in all a total of four R.F. stages, each stage con-

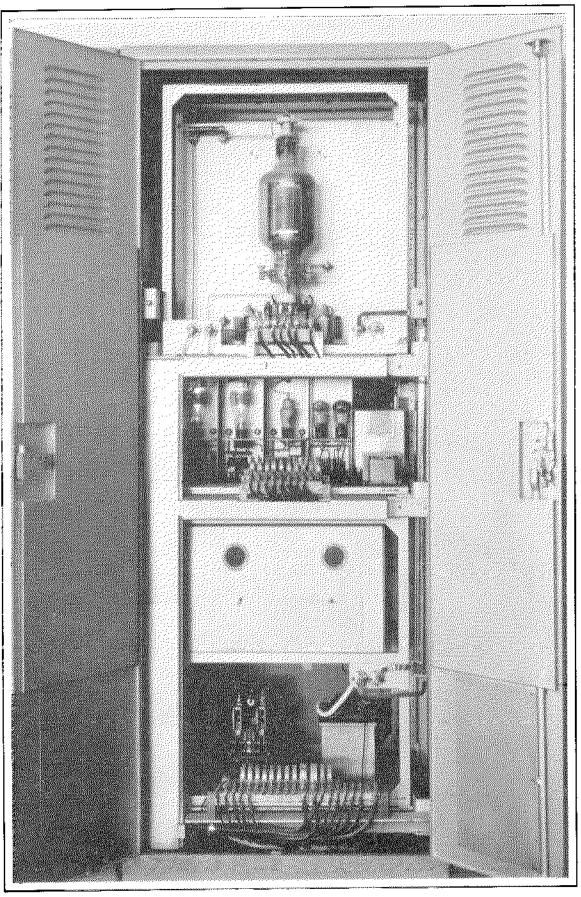


Fig. 3—H.F. Exciter, Rear View with Doors Open.

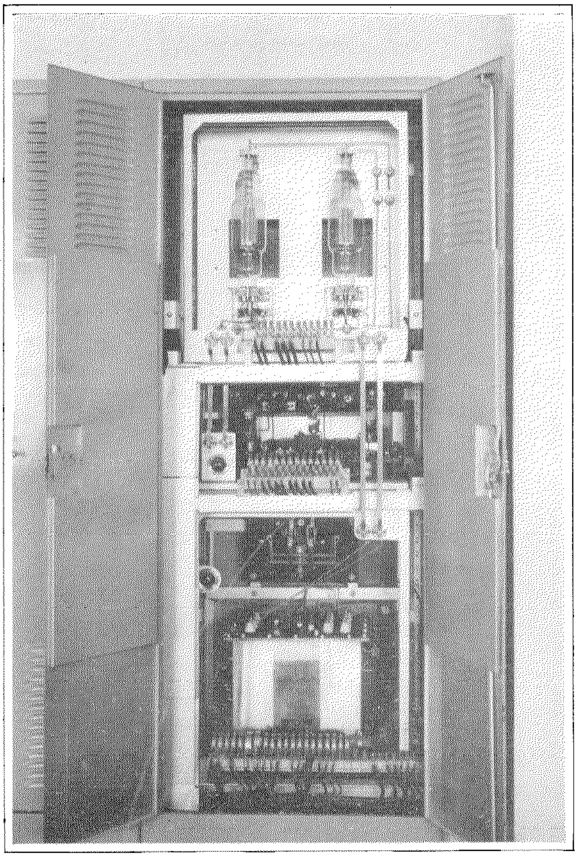


Fig. 4—L.F. Exciter, Rear View with Doors Open.

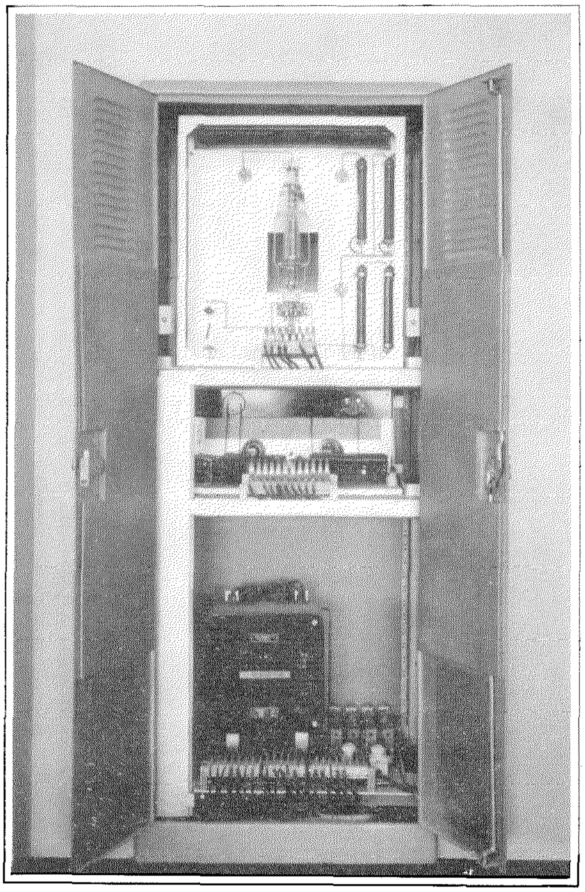


Fig. 5—Floating Carrier Unit, Rear View with Doors Open.

sisting of screen-grid valves with tuned output circuit.

(*b*) Spare R.F. exciter unit, a complete duplicate of (*a*).

(*c*) Audio frequency exciter unit (Fig. 4), consisting of a cabinet of the same dimensions as the radio frequency exciter, and including four stages of Class "A" push-pull amplification. The input and output impedances are approximately 600 ohms and 20,000 ohms, respectively. An input of −14 db. below six milliwatts is sufficient for full modulation. With such a low input level no line amplifier is required in the station, the studios at Lausanne being only twelve miles distant. As in the case of the radio frequency unit, all apparatus and valves are normally enclosed, and access to the interior is possible only when all voltages have been removed.

(*d*) Spare audio frequency exciter unit, a complete duplicate of (*c*). In the case of both the audio frequency and radio frequency exciter units, it is only necessary to operate one switch to effect a complete changeover from the working unit to the spare unit, the input and output circuits, etc. being changed over by a group of contactors.

(*e*) Floating carrier unit (Fig. 5), consisting of another cabinet of the same dimensions as those used for the exciters. It includes a dry metal rectifier energised from the audio frequency exciter to give unidirectional voltage fluctuating at syllabic frequency. This is then amplified by a two stage d-c. amplifier system, of suitable time constant, to give a reverse grid bias to the modulator. Since the latter is negatively biased towards the cut-off point when the floating carrier

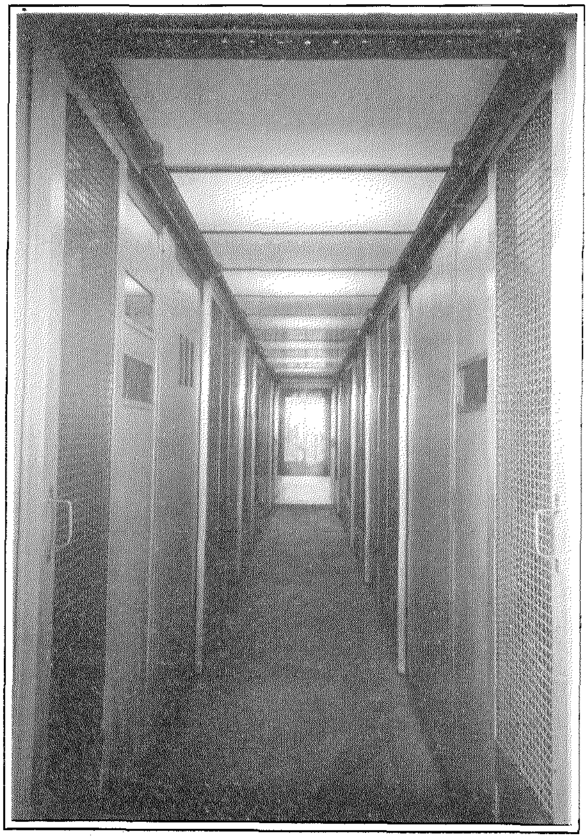


Fig. 6—Corridor of Cubicle Assembly.

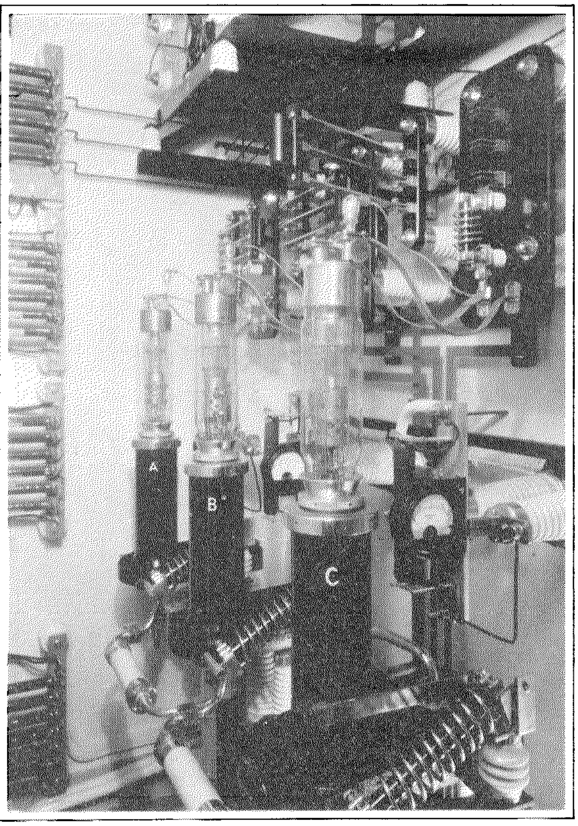


Fig. 7—Modulator Valve Cubicle.

system is in use, with no audio input the plate current in the series modulation system is very small, and the radio frequency output is correspondingly reduced, while for full audio input the reverse bias from the floating carrier unit reduces the bias on the modulator to its normal or steady carrier value, with corresponding increase in mean plate current and hence in carrier output from the modulated amplifier.

(*f*) Cubicle assembly, in which are mounted all the water cooled valves and associated equipment including the modulator and modulated amplifier, interstage circuit, power amplifier, main output circuit, and aerial tuning circuits. Of the seven cubicles comprising the line, the first five are traversed by a central corridor (Fig. 6) from which access is obtained to the individual half cubicles by sliding doors interlocked with the protective system. At the end of the corridor another sliding door gives access to the sixth cubicle, from which the seventh may be reached. The following gives an indication of the distribution of the equipment in the cubicles:

Cubicle No.	*Front*	*Rear*
1	Modulated Amplifier Valves	Modulator Valves
2	Modulated Amplifier Output	Modulated Amplifier Output
3	Power Amplifier Grid Circuit	Power Amplifier Grid Circuit
4	Power Amplifier Valves	Power Amplifier Valves
5	Power Amplifier Plate Circuit	Power Amplifier Plate Circuit
6	Power Amplifier Output Circuit	
7	Aerial Coupling and Tuning Circuits	

The efficiency of harmonic reduction from amplifier valves to aerial is such that the intensity of harmonic field strength at a distance of 5 km. from the station is only 180 microvolts/meter, representing a suppression of 71 db. on the fundamental field strength.

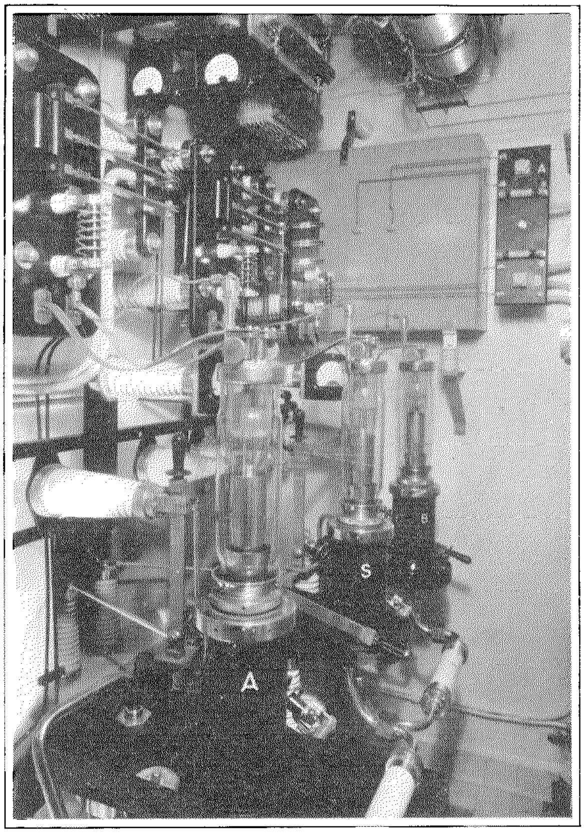


Fig. 8—Modulated Amplifier Valve Cubicle.

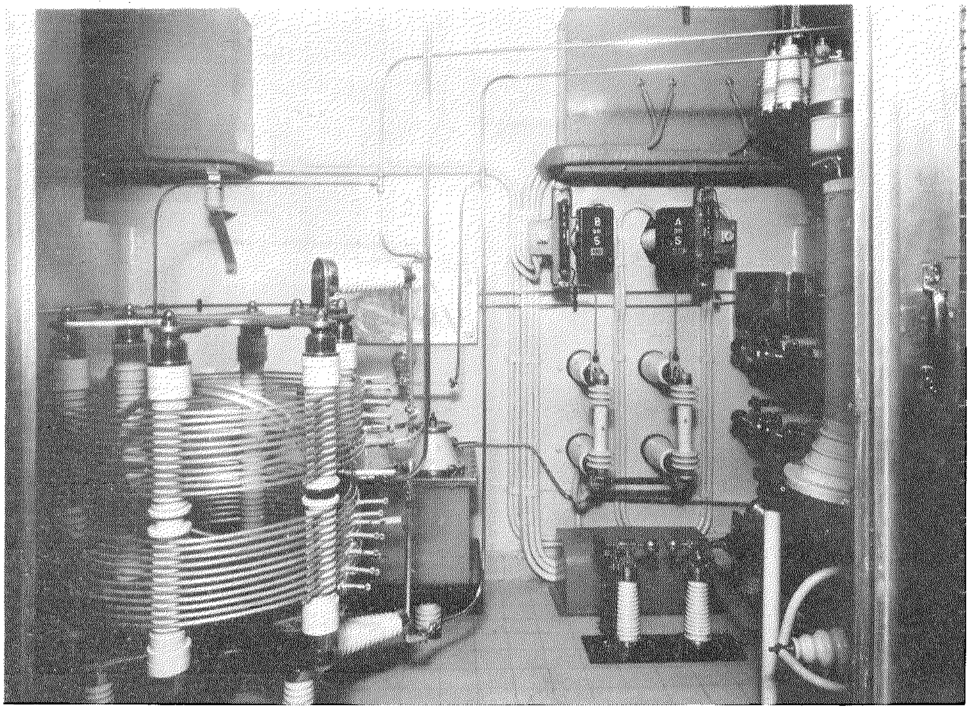


Fig. 9—Modulated Amplifier Interstage Circuit, Front Cubicle.

The circuit of the transmitter will be understood from the block schematic diagram given in Fig. 13.

The transmitter is modulated on the plates of the penultimate radio frequency amplifier. The modulator and modulated amplifier valves are operated in series from the main 18,000 volt supply for the final power amplifier. The modulator valves are on the low potential side, being interposed between the filaments of the modulated amplifier, which are insulated for high voltage, and ground. The filaments of the modulated amplifier, being at high potential to ground, are energised with a-c. from the highly insulated secondaries of transformers whose primaries are fed from the automatically regulated 380 volt, 3-phase supply. These transformers are designed for very low capacity from the secondary windings to ground, as this capacity is in shunt to the output of the modulators and consequently affects the frequency response. The transformers are Scott connected, so reducing hum arising from the a-c. heating of the filaments.

The power supply system of the transmitter is shown schematically in Fig. 14.

The main power supply for the station is derived from 8,000 volt, 3-phase, 50 cycle mains. Two sources of supply are available from separate power stations, and are brought to the station by separate feeders. The main incoming power supply is branched, one part being taken direct to the transformer for the 18,000 volt Brown-Boveri mercury arc rectifier, and the other part being stepped down to give a 380 volt supply for the motor generators, pumps, fans, and the rectifiers feeding the exciter and floating carrier units.

The general construction of the cubicles and method of mounting valves and apparatus will be gathered from the illustrations. All valves are water cooled, the water supply being taken through porcelain hose coils situated in the basement directly underneath the cubicles.

The modulator cubicle (Fig. 7) is equipped with three No. 4053-A low impedance valves. Two of these are normally connected in parallel, the third being a spare.

The modulated amplifier cubicle (Fig. 8) is equipped with two No. 4009-A valves, operating in push-pull, and with an additional spare valve which can be switched to either side of the push-pull circuit as required. Figs. 9 and 10 show the modulated amplifier interstage circuit cubicles.

There are two power amplifier valve cubicles (Fig. 11), one on each side of the corridor, each containing a pair of No. 3030-A valves in parallel, together with a spare pair of valves. The two cubicles form the two sides of a push-pull system, and in either cubicle any two of the four valves can be used together. The switching system governing these valves includes not only the electrical but also the water circuits.

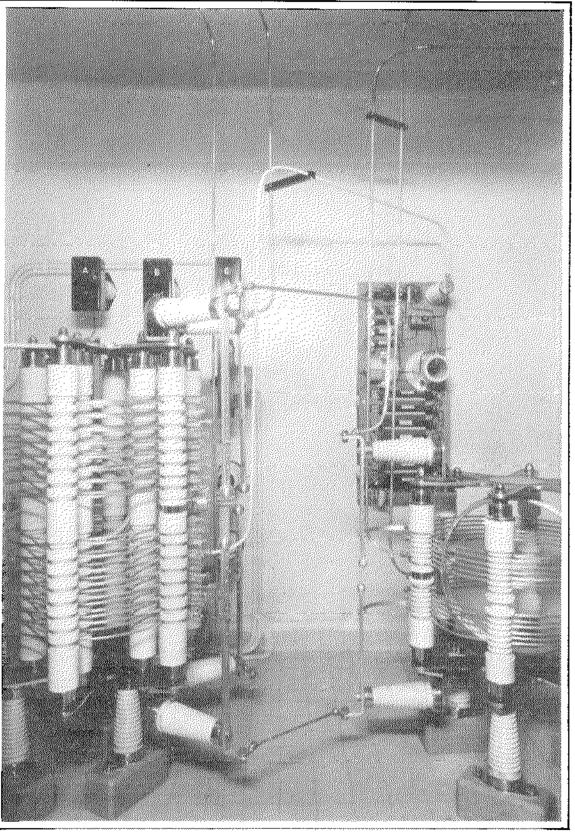


Fig. 10—Modulated Amplifier Interstage Circuit, Rear Cubicle.

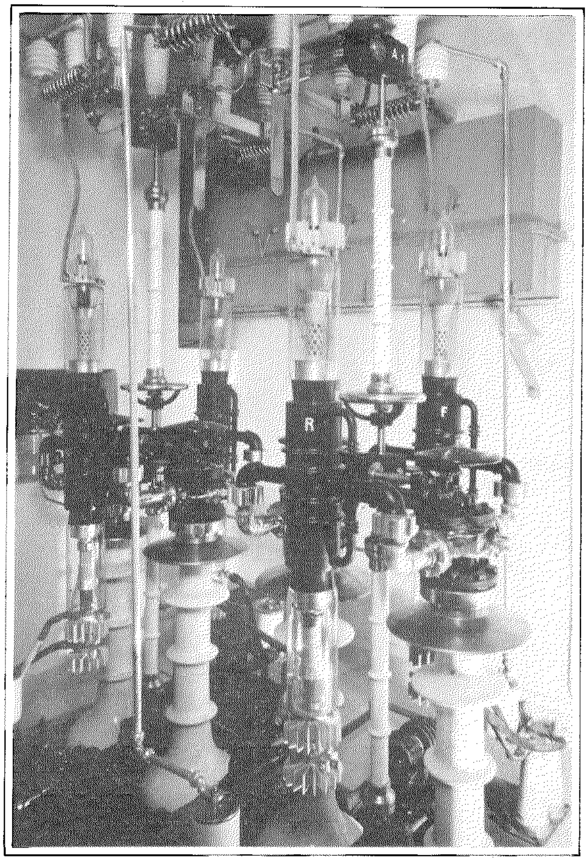


Fig. 11—Power Amplifier Valve Cubicle.

Cubicle No. 6 (Fig. 12) contains two tuned output circuits inductively coupled, working into a filter circuit of 600 ohms impedance, situated in cubicle No. 7. This value of impedance was adopted so that if the aerial system should later be changed to one requiring transmission line feed, it will be possible to connect the feeder directly to the filter output terminals.

Cubicle No. 7 contains the harmonic filter and the antenna tuning and coupling circuit. The filter includes series and shunt elements, and the antenna coupling circuit is a closed tuned circuit inductively coupled to the aerial. The aerial is tuned by a tapped coil and a shortening condenser. The high frequency transformers providing the inductive coupling between the two tuned output circuits and between the antenna coupling circuit and the antenna are fitted with earthed electrostatic shields.

To accommodate the equipment for the switching, fusing, and metering of these supplies, a

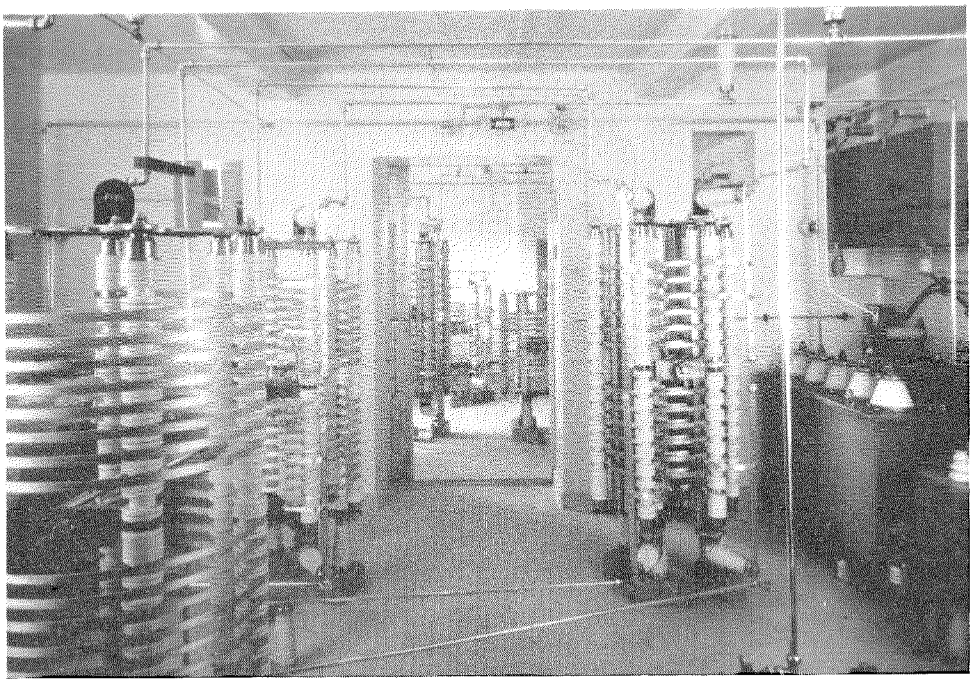


Fig. 12—Power Amplifier Output and Aerial Circuit Cubicles.

power board (Fig. 15) is provided in the Transmitter Hall. This board is of dead front panel construction, approximately 6 m. long × 2.2 m. high × 1.4 m. deep, and is divided into six main sections with controls for the following:

(1) Incoming 8,000 volt, a-c. supply;

(2) 380 volt, a-c. supply, non regulated, to motors, and 380 volt, a-c. supply stabilised by automatic induction regulator, to the low power supply unit rectifiers;

(3) 28 volt d-c. and 10–12 volt d-c. filament supplies from generators;

(4) 550 volt d-c. and 1,200/2,500 volt d-c. grid bias supply from generators;

(5) 28 volt generator changeover switching;

(6) 2,500 volt generator changeover switching.

Provision is made on the board for automatic control of the time taken for building up the excitation of the 28 volt generator to its normal value, in order to ensure that the power valve filaments are not brought up to full brilliancy too quickly. The external finish of the board is grey, to line up with the finish on the exciter units and control desk which are in the same room.

High tension supply for the modulation and power amplifier systems is derived from a 400 kW. 18,000 volt Brown-Boveri rectifier of the grid controlled mercury arc type. This is mounted, together with its auxiliary oil and molecular vacuum pumps and cooling system, in the basement of the station, together with the 18,000 volt smoothing system and the rectifier H.F. protective filter (Fig. 16). The full transformer voltage is always applied to the rectifier, and adjustment of the d-c. voltage is obtained by phase control of the grid voltage. The grids are also interconnected with the protective system to switch off the rectifier momentarily in the event of a back fire in the rectifier or a flash arc discharge in the transmitter valves.

The high tension filter system is divided into five branches feeding separately the modulating stage and each of the four power amplifier valves. The division of the filter gives increased protection against short circuits and reduces intermodulation between stages.

Grid bias, screen, and anode voltage supplies for both the high frequency and audio frequency exciter units, and also the anode supply for the floating carrier unit are obtained from a "Low Power Supply Unit" (Fig. 17) consisting of a group of metal rectifiers for the voltages of 2,500, 850, 425 and −150.

These rectifiers are all operated from the 380 volt supply taken through the automatic induction regulator. Each rectifier has its own working and spare transformer, arranged for changeover by a manually operated switch, also a spare rectifier element. The unit includes the necessary

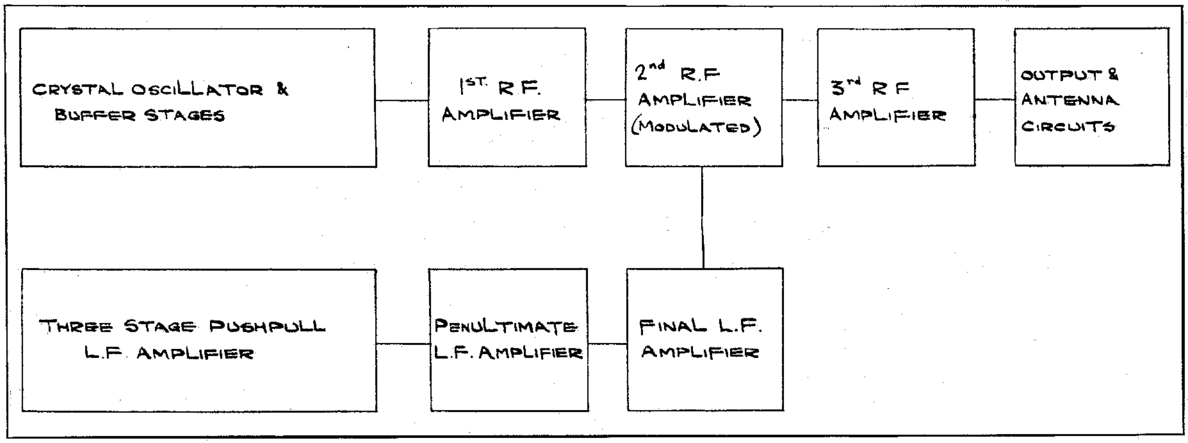

CRYSTAL OSCILLATOR & BUFFER STAGES
1ST R.F. AMPLIFIER
2nd R.F AMPLIFIER (MODULATED)
3rd R F AMPLIFIER
OUTPUT & ANTENNA CIRCUITS
THREE STAGE PUSHPULL L.F. AMPLIFIER
PENULTIMATE L.F. AMPLIFIER
FINAL L.F. AMPLIFIER

Fig. 13—Transmitter Circuit, Block Schematic.

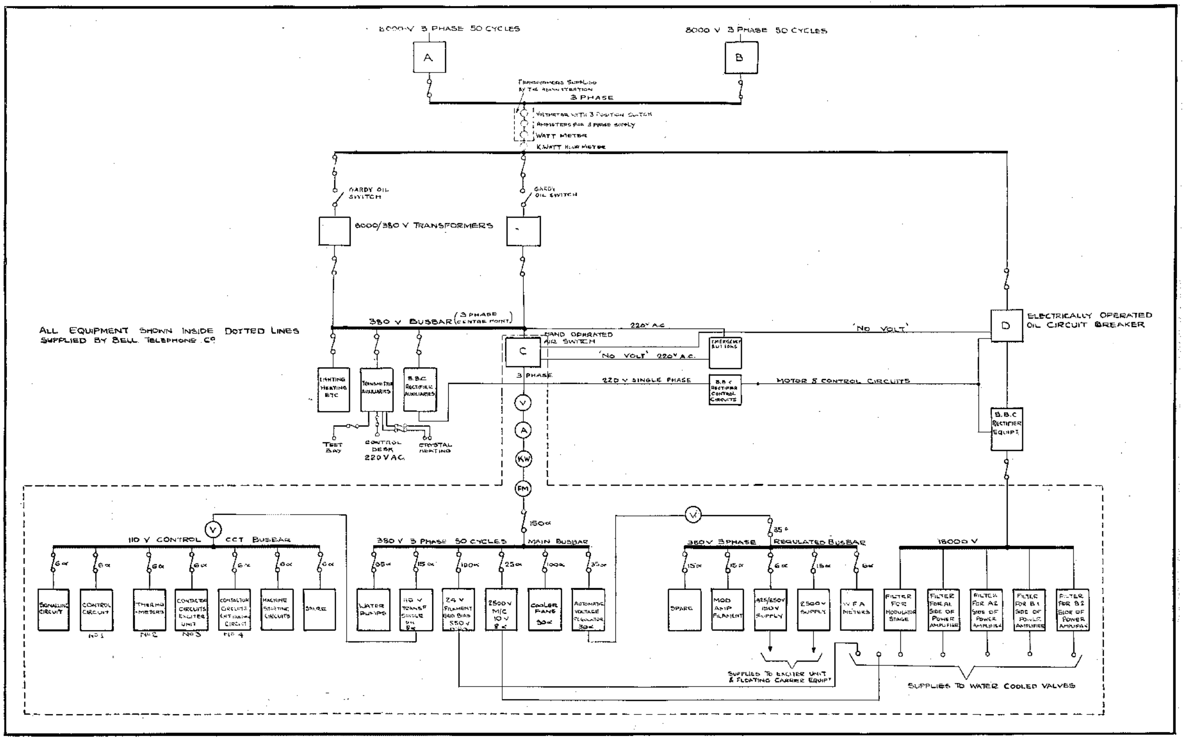

6000 V 3 PHASE 50 CYCLES
A
8000 V 3 PHASE 50 CYCLES
B
TRANSFORMERS SUPPLIED BY THE ADMINISTRATION
3 PHASE
VOLTMETER WITH 3 POSITION SWITCH
AMMETERS FOR 3 PHASE SUPPLY
WATT METER
K.WATT HOUR METER
GARDY OIL SWITCH
GARDY OIL SWITCH
6000/380 V TRANSFORMERS
ALL EQUIPMENT SHOWN INSIDE DOTTED LINES SUPPLIED BY BELL TELEPHONE Cº
380 V BUSBAR (3 PHASE CENTRE POINT)
220V A.C
HAND OPERATED AIR SWITCH
C
'NO VOLT' 220V A.C.
EMERGENCY BUTTONS
'NO VOLT'
D
ELECTRICALLY OPERATED OIL CIRCUIT BREAKER
3 PHASE
220 V SINGLE PHASE
B.B.C RECTIFIER CONTROL CIRCUITS
MOTOR & CONTROL CIRCUITS
B.B.C RECTIFIER EQUIPT
LIGHTING HEATING ETC
TRANSMITTER AUXILIARIES
B.B.C RECTIFIER AUXILIARIES
TEST BAY
CONTROL DESK 220 V AC
CRYSTAL HEATING
V
A
KW
FM
150A
V
110 V CONTROL CCT BUSBAR
6A
SIGNALLING CIRCUIT
CONTROL CIRCUIT Nº1
THERMO-METERS Nº2
CONTACTOR CIRCUITS EXCITER UNIT Nº3
CONTACTOR CIRCUITS EXT. HEATING CIRCUIT Nº4
MACHINE STARTING CIRCUITS
SPARE
380 V 3 PHASE 50 CYCLES MAIN BUSBAR
35A
15A
100A
25A
100A
35A
WATER PUMPS
110 V TRANSF SINGLE PH 8A
24 V FILAMENT GRID BIAS 550 V
2500 V M/C 10 V 8A
COOLER FANS 30A
AUTOMATIC VOLTAGE REGULATOR 30A
V
35A
380 V 3 PHASE REGULATED BUSBAR
15A
15A
6A
15A
6A
SPARE
MOD AMP FILAMENT
425/850V 150V SUPPLY
2500 V SUPPLY
W.E.A METERS
SUPPLIES TO EXCITER UNIT & FLOATING CARRIER EQUIPT
18000 V
FILTER FOR MODULATOR STAGE
FILTER FOR A1 SIDE OF POWER AMPLIFIER
FILTER FOR A2 SIDE OF POWER AMPLIFIER
FILTER FOR B1 SIDE OF POWER AMPLIFIER
FILTER FOR B2 SIDE OF POWER AMPLIFIER
SUPPLIES TO WATER COOLED VALVES

Fig. 14—Power Supply Schematic.

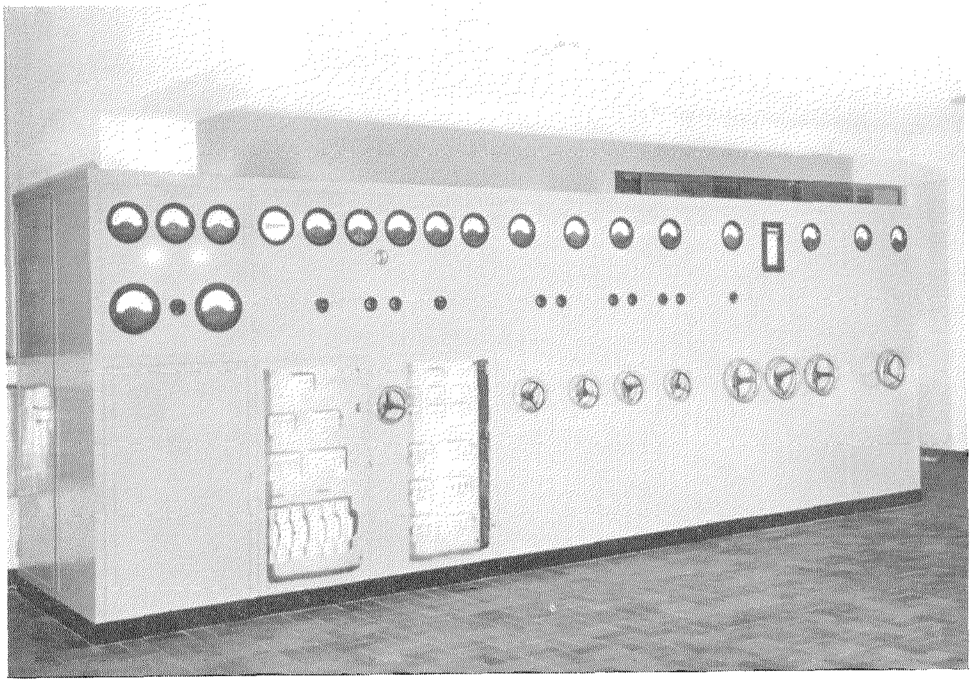


Fig. 15—Machine Power Board.

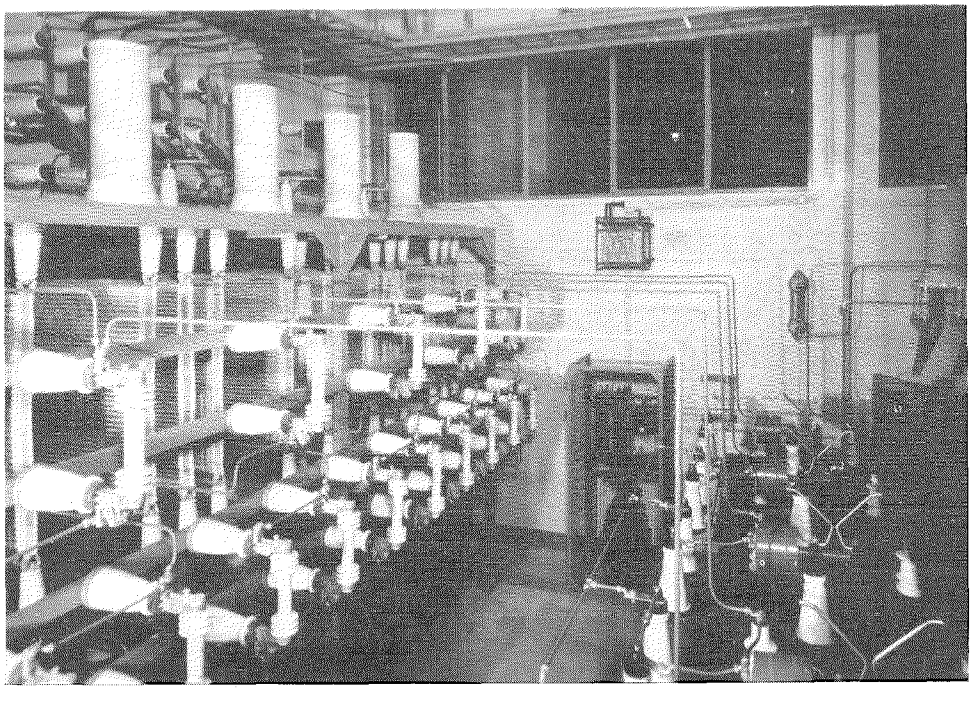


Fig. 16—18,000 Volt Rectifier Protective Filter, and Isolator System.

filter circuits for the various outputs. As in the case of the exciter units, all apparatus is completely enclosed but is accessible by opening the doors which are interlocked with the protective system to remove all dangerous voltages. Handwheels on the front of the unit operate changeover switchgear isolating the exciter units not in service.

The complete low power supply unit, including the rectifier elements, transformers, smoothing equipment, and an associated contactor rack, is installed in the machine room behind the exciter units.

The valve water cooling system is of the closed circuit type using distilled water cooled by air blast radiators. Piping, pumps, etc., are all of non-ferreous material. Where the water channel changes from an electrically conducting medium to a non-conducting medium, renewable thin lead sleeves are provided to take up the electrolytic action which inevitably occurs at such points. The system dissipates a power of the order of 300 kW.

Control and metering of the water supply to the various valve units is carried out at the water control board located in the Transmitter Hall. This control board is of the panel type, 3.2 m.×2.2 m., and is divided into four sections. On it are mounted actuating handles for the cocks controlling the total flow and the separate flow to each valve cubicle, also water flow meters and outlet temperature thermometers for each branch circuit.

The flow meter circuits are interconnected with the electrical protective system in a manner such that the voltages cannot be switched on until normal water circulation has been established.

As already mentioned, the porcelain water coils (Fig. 18) which provide the high resistance path between the valve jackets and ground are installed in the basement, directly beneath the valves they serve. They are surrounded by strong glass partitions so that in the event of an accidental breakage while the transmitter is

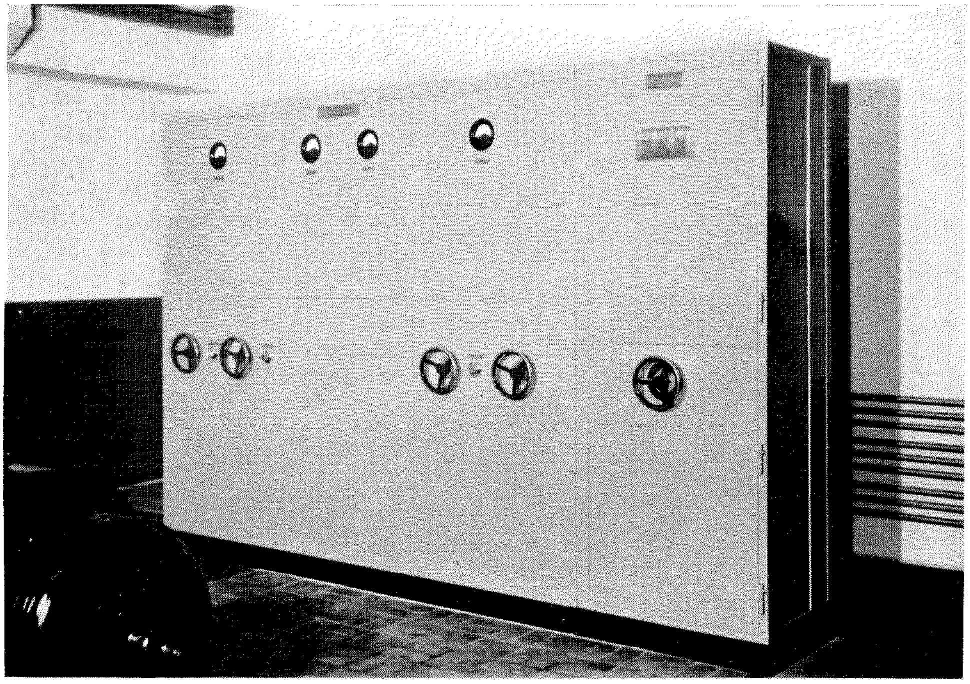


Fig. 17—Low Power Supply Unit.

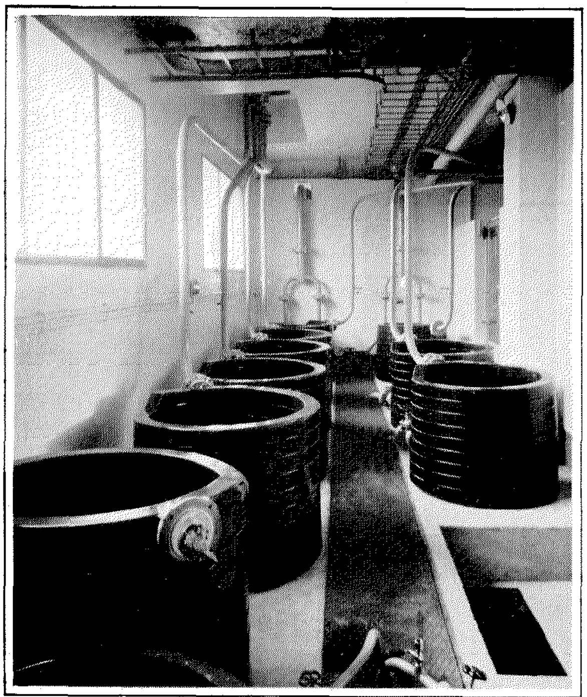


Fig. 18—Water Coils Installed in Basement.

working there can be no danger to personnel from jets of water at high potential.

The operations for bringing the transmitter into service are performed at the power board in the transmitter room, except the application of the main high voltage. The latter is applied and regulated from a control desk which is fitted also with meters and facilities for general supervision of the equipment while in operation.

The control desk (Fig. 19) is of metal construction, its dimensions being approximately 1.9 m. long × 1 m. wide by 1.13 m. high. It is finished in grey cellulose to line up with the exciter units and power board. The equipment on the desk includes the following:

(1) Meters for reading all the important valve voltages for both the exciter units and the power amplifier;

(2) Switches for the control and regulation of the 18,000 volt mercury arc rectifier;

(3) An "emergency stop" button enabling the whole station to be shut down instantaneously;

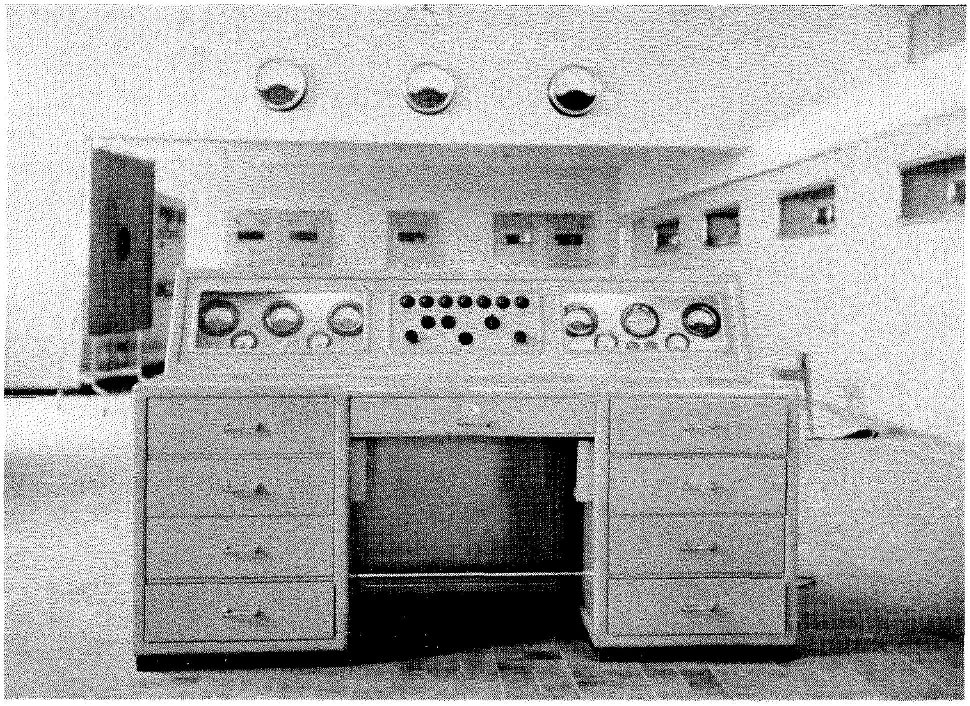


Fig. 19—Control Desk.

(4) Signal lamps to indicate any failure in the protective systems;
(5) Programme level indicator;
(6) Modulation meter indicating depth of modulation at the output of the transmitter;
(7) A signal lamp giving warning of over-modulation;
(8) A monitoring loud speaker which can be connected to any one of the monitoring points at the outputs, respectively, of the audio frequency exciters, the modulated amplifier, and the power amplifier;
(9) An hour meter indicating the operating time of the power amplifier valves.

In order to facilitate the maintenance of a high standard of transmission quality, a bay of monitoring and testing apparatus (Fig. 20) is mounted in the transmitting room available for routine measurements of performance. The equipment is permanently connected to enable measurements to be made quickly and easily at a number of points in the transmitter. The following are some of the observations which can be made at the test rack, as a routine operation:

(1) Percentage modulation on both positive and negative peaks;
(2) Programme monitoring with high speed volume indicator;
(3) Carrier noise level;
(4) Amplitude distortion in low frequency and high frequency amplifiers (harmonic content);
(5) Noise and hum level of audio amplifiers;
(6) Audio frequency response curves;
(7) Modulation curves in conjunction with the modulation meter mounted on the transmitter;
(8) Gain of low frequency amplifiers;
(9) Examination for symmetry of wave form by cathode ray oscillograph;
(10) Depth of modulation by cathode ray oscillograph;
(11) Low frequency wave form examination by cathode ray oscillograph.

The modulation indicator can be left in continuous operation and, associated with it, there is a device to indicate over-modulation by flashing of a lamp.

The aerial is of the high T type, slung between two insulated, self-supporting steel towers 125 meters high and spaced 200 meters apart. The earth system consists of a buried copper wire network covering an area of 200 meters × 260 meters.

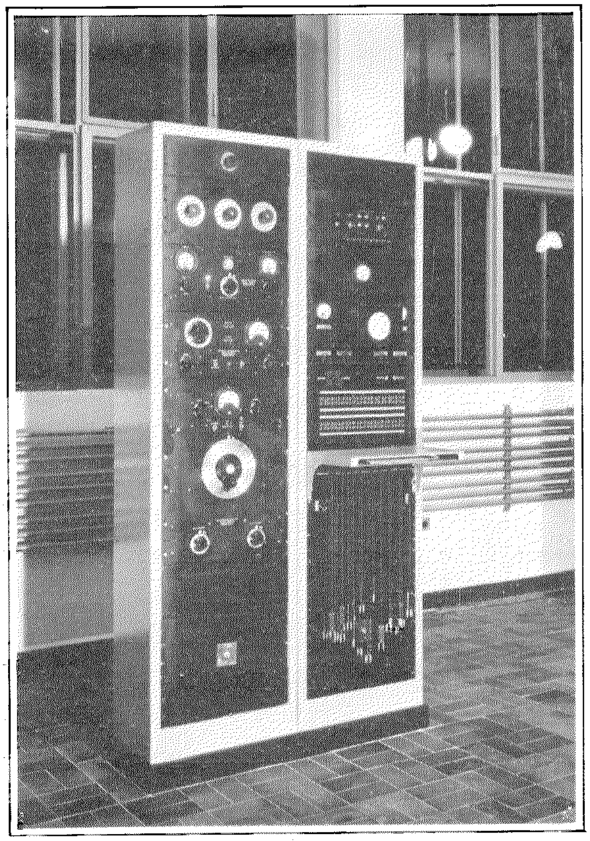


Fig. 20—Test Rack for Routine Testing.

The overall performance of the transmitter, both in regard to transmission quality and reliability, meets fully the high standards required by the Swiss Broadcasting Service. The frequency response curve lies between ±2 db. between 30 and 10,000 cycles per second, and the audio frequency harmonic content due to amplitude distortion is of the order of 4% R.M.S. at 85% modulation.

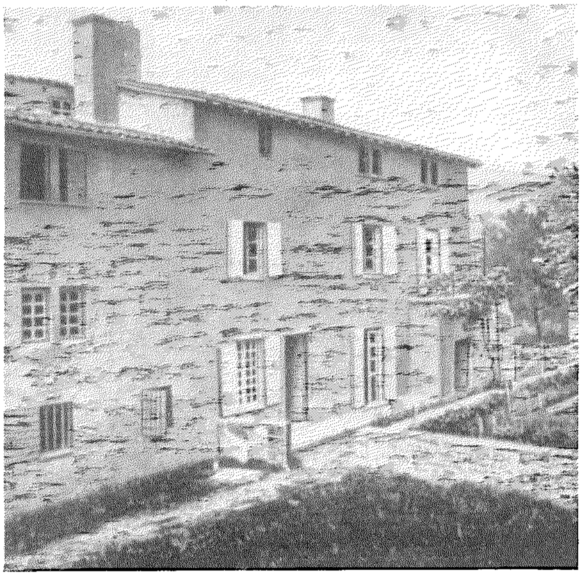
The accomplishment of the work of extension and modernisation in the short period of ten months without any interruption to the transmissions from the station entailed the closest cooperation between the Administration and the contractors, and was secured through the assistance of the station superintendent, Mr. R. Piece, and his staff.

Centennials of T

André Marie Ampère

ANDRÉ MARIE AMPÈRE, one of the greatest scientists of all time, "sought the truth, elevated ideas, general principles, and he preferred them if they could be directly applied." He contributed to the idea of the electric telegraph, and his memoirs show that his investigations related to "transcendental mathematics, applications to mechanics, electricity and magnetism, optics, the theory of gases, molecular physics, animal physiology, the theory of the earth, metaphysics and psychology."[1]

"He discovered the mechanical action between electric currents, and he established mathematically and by physical demonstration the law of that action. This Maxwell declared to be one of the most brilliant achievements in science; for the whole, theory and experiment, had 'leaped full grown and fully armed from the brain of the Newton of electricity,' perfect in shape, unassailable in accuracy, and summed up in a formula from which all the phenomena could be deduced—the cardinal formula in electrodynamics."



Ampère's Home at Polémieux Donated in 1928 by Colonel Sosthenes Behn and the Late Mr. Hernand Behn to the Société Française des Electriciens as a Symbol of Universal Tribute to this Great French Genius

"Thanks chiefly to the efforts of Mascart, the name of Ampère has been adopted universally as the designation of the unit of electric current, and thanks largely to Joubert his memoirs have been reproduced for posterity. Yet, if there is ever to be a temple of scientific research in Paris, devoted in the noblest sense, to the welfare of mankind, France may appropriately write across its portal the name of Ampère, for his gifts to humanity can be repaid only in contributions that further the purpose for which he lived."

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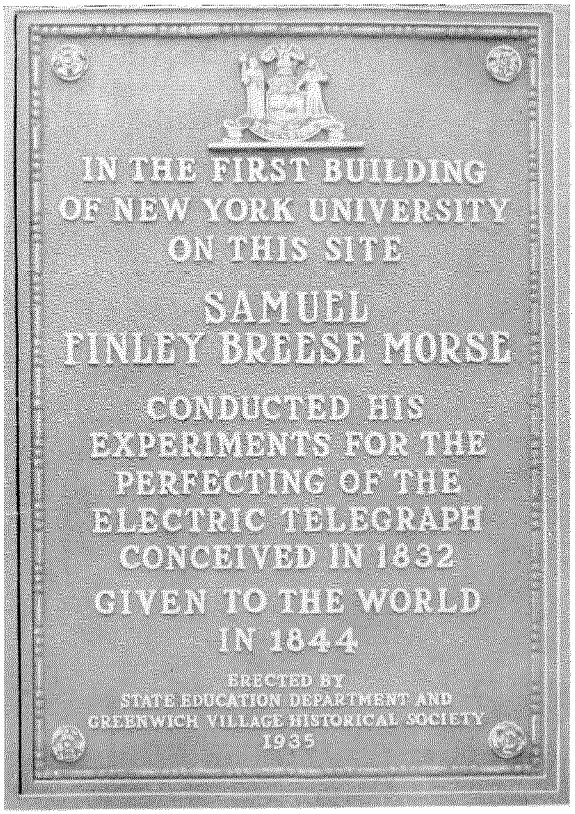
[1] Quotations are from "Pioneers of Electrical Communication—André Marie Ampère—II," by Rollo Appleyard, *Electrical Communication*, January, 1927.

ommunication Pioneers

Samuel Finley Breese Morse

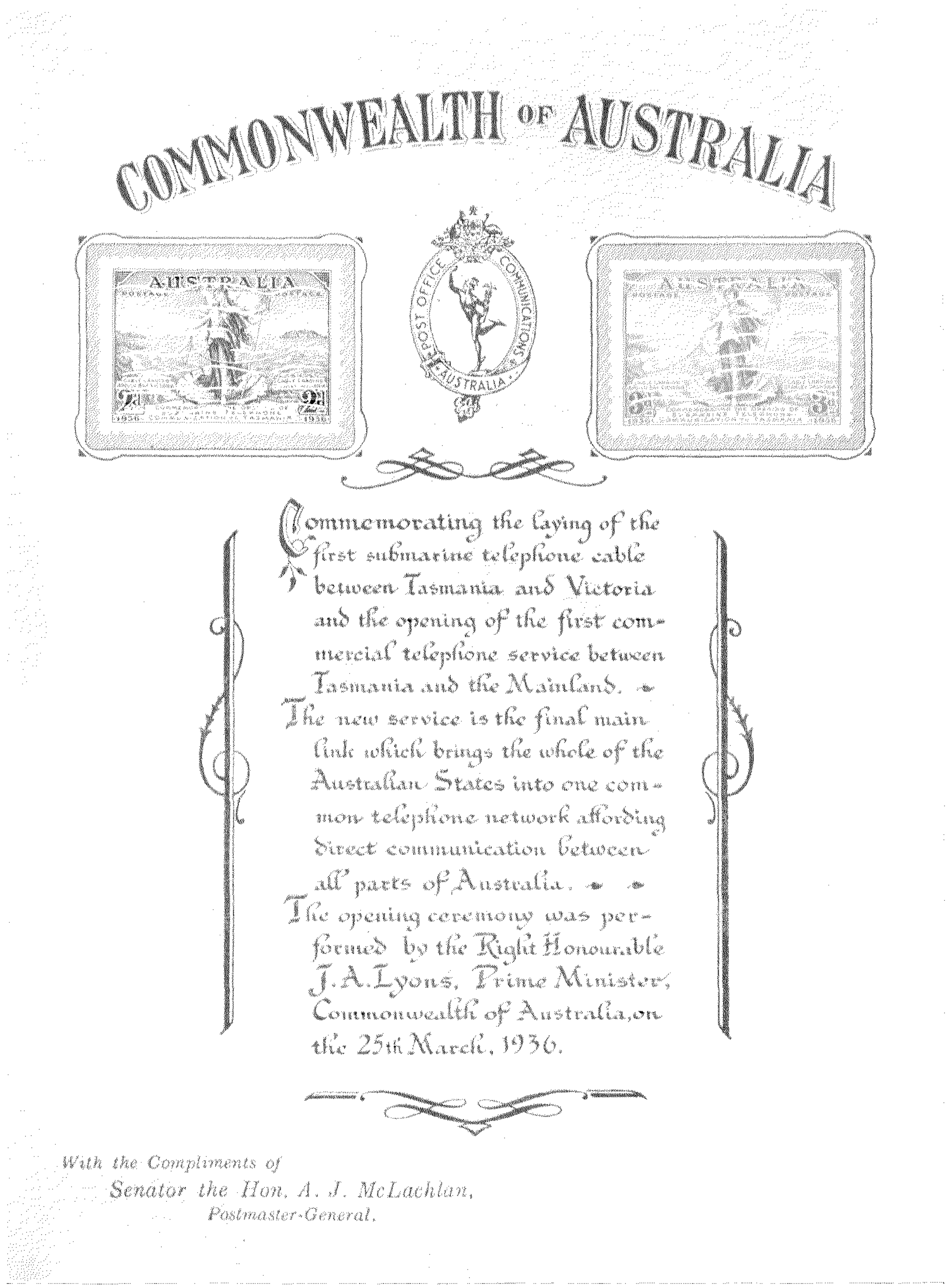
SAMUEL FINLEY BREESE MORSE, founder of the National Academy of Design, the first in America to occupy a chair of fine arts, and a distinguished portrait painter, carried on his original experiments with the telegraph at New York University in Washington Square, New York City, a century ago. He moved into the University building in 1835 before it was finished and, the stairways not being completed, his sitters, for a time, were discouraged from coming to his studio. The enforced leisure gave him an opportunity to experiment with the idea of the telegraph which he had conceived in 1832. He improvised a telegraph instrument, now in the Smithsonian Institution in Washington, and demonstrated it to friends early in 1836. The inventor continued his experiments and, at a select gathering in the Geological Cabinet, a museum of the University, on January 24, 1838, publicly demonstrated a perfected machine. When Morse asked for a message to transmit, one of the guests suggested the now famous words constituting a facetious command: "Attention, the Universe: By Kingdoms, Right Wheel!" This message was traced by four inked styluses on a paper tape and constituted a perfect quadruplicate record.



Courtesy of New York University

Bronze Memorial Tablet, Erected May 28, 1935, to Mark the Site of the Original New York University Building in New York City where Morse Sent the First Message by Electric Telegraph

Morse viewed the telegraph realistically, felt certain of its practicability and experimented extensively with batteries, overhead lines and cables. Due largely to his efforts, the system developed by his company, the Magnetic Telegraph Company, was adopted throughout the world and is today being used in rural areas virtually unchanged.



COMMONWEALTH OF AUSTRALIA

Commemorating the laying of the first submarine telephone cable between Tasmania and Victoria and the opening of the first commercial telephone service between Tasmania and the Mainland.

The new service is the final main link which brings the whole of the Australian States into one common telephone network affording direct communication between all parts of Australia.

The opening ceremony was performed by the Right Honourable J. A. Lyons, Prime Minister, Commonwealth of Australia, on the 25th March, 1936.

With the Compliments of
Senator the Hon. A. J. McLachlan,
Postmaster-General.

Commemoration Card issued by the Commonwealth of Australia. (On the Card Itself, the Postage Stamps are Red and Blue, respectively.)

Australia-Tasmania Cable

"TASMANIA'S separation is ended," quotes *The Mercury*, one of the leading newspapers of Tasmania, following the inauguration of telephone service over the new Australia–Tasmania cable on Wednesday, March 25, 1936. The service was opened officially by the Prime Minister, whose voice was transmitted with perfect clarity through the cable from Albury to the gathering at Hobarts Hotel, Tasmania, assembled to take part in the inauguration ceremony.

"The opening of this service tonight marks the ultimate achievement of an Australian telephone service which is truly national," said the Prime Minister, "and it is, therefore, with feelings of pride and deep gratification that I declare the line between Tasmania and the mainland open for regular business."

The communication channel requirements for which the cable is designed are five telephone circuits, seven duplex telegraph circuits, and a channel for the transmission of broadcasting programmes.

The methods employed to provide the required number of circuits may be briefly described as follows:

A specially designed carrier telephone system, having its terminal equipment at Apollo Bay and Stanley and a repeater station at King Island, providing five carrier telephone channels and a physical or voice frequency channel, the latter being brought out at the King Island Repeater Station so as to provide communication with Currie in addition to carrying through traffic. Three of the channels are extended to Melbourne on the Victorian side and to Launceston on the Tasmanian side. This extension is made by means of two further carrier telephone systems, one system providing three channels between Melbourne and Apollo Bay and a second providing three channels between Stanley and Launceston, with one channel permanently extended to Hobart. These systems are 3-channel open-wire systems of the type already in extensive use in Australia. Each of the three carrier telephone systems is of the single sideband, suppressed carrier type.

The remaining two telephone channels in the cable will, for the present, remain as spares. A broadcast programme circuit is obtained by means of a separate carrier telephone system. This operates in a frequency range above that of the carrier channels, and is thus operated simultaneously over the same open-wire lines and cable. It has its terminal equipments at Melbourne and Hobart, with repeaters at all intermediate stations. Seven duplex telegraph circuits will be obtained by applying a voice frequency telegraph system to one of the carrier telephone channels. Further channels up to a total of sixteen can be added later if desired. The voice frequency telegraph equipment will be located at Melbourne and Launceston, certain of the telegraph channels being extended to Hobart by means of composite equipment.

The submarine cable section of the system represents an advance in several respects on previous achievements in the art of telecommunication, and is the first submarine cable of this type to be equipped with a repeater station at its mid-point. The repeater equipment compensates for a cable attenuation of about 70 db. in each cable section at 42.5 kc., and amplifies the telephone channels simultaneously by means of one of the first commercial applications of the Black "negative feedback" type of amplifier. The cable is also the first submarine cable of comparable length to be operated with balanced two-wire carrier channels, and an important problem was that of designing and constructing balancing networks which would take full advantage of the uniformity of cable characteristics obtained by extremely careful manufacture of the cable, and thus enable the possibility of balanced channels to be fully exploited.

The system was designed and the equipment manufactured by Standard Telephones and Cables, Limited. The cable was manufactured and laid by Messrs. Siemens Bros. & Co., Ltd.

Ten Years' Experience In The Maintenance of Rotary Automatic Equipment in Spain

By G. N. SAURWEIN,
Director of Construction and Maintenance,
and MANUEL MARÍN,
General Supervisor of Maintenance, Compañia Telefónica Nacional de España, Madrid, Spain

BEFORE entering into a discussion of the maintenance of the Rotary Automatic equipment in Spain, a general impression of the telephone situation as it existed in this country when the Compañia Telefónica Nacional de España was granted its concession will be of interest. Only with a realization of what this situation was, can the reader form an idea as to the size of the task which was faced in the training of a maintenance organization.

The first telephone communication in Spain took place in Barcelona on December 16, 1877, one year after the invention of the telephone, but notwithstanding this auspicious beginning, the development of the service was extremely slow. The difficulties were the lack of any definite national policy in coordinating the many independent and municipal enterprises which were attempting to operate a telephone service, and the terms under which the former were licensed to do business—terms which effectively stifled any tendency to build for the future. The Spanish Government, on August 25th, 1924, entered into a contract with the Compañia Telefónica Nacional de España for the construction and operation of a unified national telephone system. The following paragraph taken from the Decree authorizing the execution of the contract gives an idea of the conditions at the time:

> "The causes that have brought about the present telephone situation in our country must be looked for in the heterogeneous character of the system as a whole; in the voluminous, varied and even contradictory and antiquated special legislation; in the veritable mosaic of administrative contracts which, inspired by said legislation, regulate the numerous concessions operating to-day; and finally, in the fundamental error, so far as this service is concerned, of conceding the construction to an entity, and, in consideration therefore, granting to it the rights of operation, conditional upon the gratuitous reversion (of the plant) to the State in a period of greater or less length."

One of the outstanding characteristics of the contract was the requirement that within five years from the date on which it took effect automatic service should be established in the seventeen principal cities of the country, and that high grade long distance facilities should be extended throughout the peninsula to all of the provincial capitals and to all county seat towns of more than 8,000 inhabitants. This, in addition to presenting a construction problem of major importance, emphasized the need of developing a maintenance force capable of keeping the new plant operating at maximum efficiency. The formation of an organization for the maintenance of automatic exchange equipment was no easy task, since the experience of the personnel available had been gained in working with a large diversity of antiquated apparatus and markedly different methods of operation. These employees had been accustomed to doing their work according to their own ideas, and any system of definite and unified method of procedure was completely unfamiliar to them.

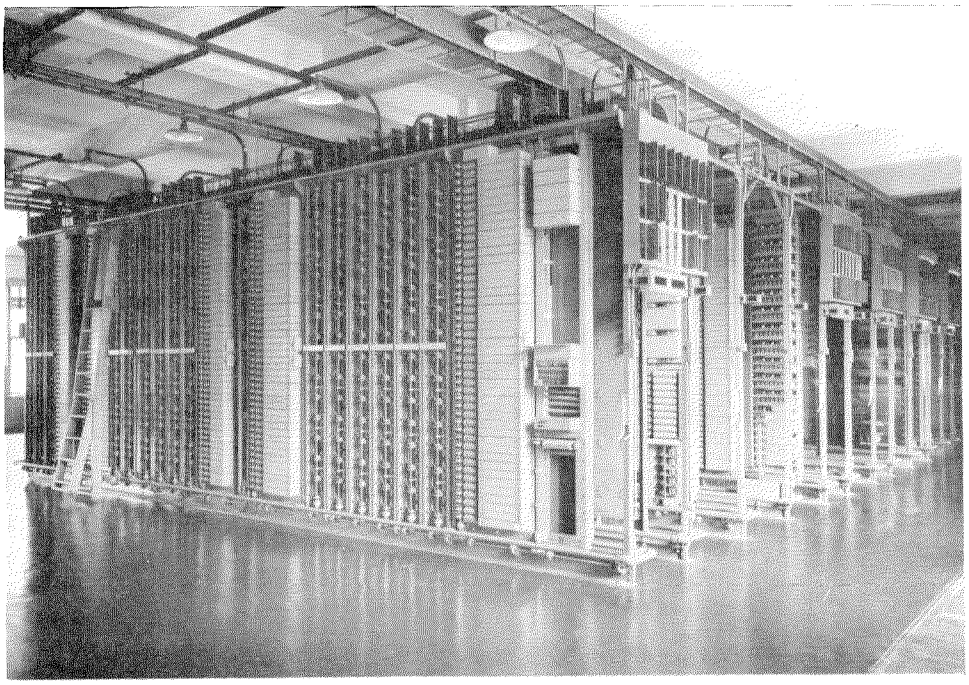
To give a concrete idea of the amount of work accomplished in the early years of the Company, the following figures are shown:

	August 1924	December 1935	Increase
Number of Rotary Automatic Exchanges, Type 7-A	—	26	**26**
Number of Rotary Automatic Exchanges, Type 7-B	—	22	**22**
Number of Telephone Exchanges	627	3,110	**2,483**
Number of Telephones Connected to Automatic Exchanges	—	217,702	**217,702**
Total Number of Telephones	78,525	329,130	**250,605**
Kilometers of Long Distance Circuits	40,000	336,991	**296,991**

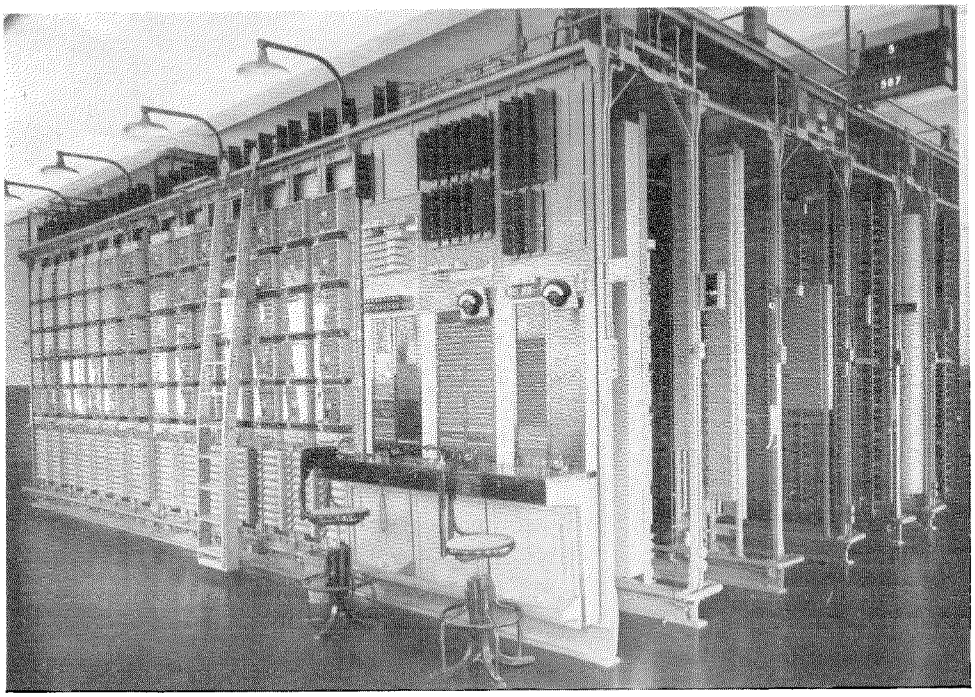
In addition to the development indicated above, there was also involved the installation of repeater stations, of underground distribution systems, of submarine cables, and of radiotelephone stations connecting the network of the peninsula with cities in North Africa, the Balearic and Canary Islands, and South America.

Coincident with the undertaking of this construction program, the company established a school for the training of personnel for all branches of its activities, and an important section of this school was that occupied with instruction in the theory and practice of the 7-A Rotary Automatic Equipment, where men were trained to take charge of maintenance in the automatic exchanges being built in the important cities throughout the country. For the theoretical instruction incomplete schematic circuits were used in which the relays and other pieces of apparatus were indicated but the electrical connections were omitted. The students traced the progress of the establishment of a communication by drawing in these connections in the order of their use. A conventional system of circuit diagrams was adopted, making it easy to see, at any step during the progress of a selection, which relays and magnets were in an operated, and which were in a normal condition. These preliminary studies of the theory of operation of component parts of the equipment were followed by further studies of the Rotary system as a whole, as well as of special features of the system not utilized in the establishment of a normal connection.

To provide for practical instruction a shop was set up where the students were trained to mount and dismount apparatus, to use the tools and measuring instruments necessary for the adjustment of switches, relays, etc., and at the same time to become acquainted with the adjustment constants and limits specified by the manufacturer. Finally, with a model of the 7-A system built specially for demonstration and study, incorporating line finders, registers, link circuits, 2nd and 3rd group and final selectors, practical instruction was given in the operation of the equipment and the detection of troubles



7-A Rotary Automatic Equipment, Madrid—Gran Via Exchange



7-A Rotary Automatic Equipment, Madrid—Gran Via Exchange

previously introduced by the instructors.

In the instruction of the student mechanics, special care was taken to instill in them the idea that the maintenance of automatic equipment consists in keeping its component parts within the limits of adjustment necessary for their proper functioning. In general, this result may be accomplished in two ways, the corresponding methods being known respectively as preventive maintenance and corrective maintenance.

Preventive maintenance is based upon the use of appropriate systematic or routine tests of the equipment under conditions more severe than those of normal operation, in order that the weak points which show up may be corrected before they have had a chance to cause interruptions in the service. This same procedure also, of course, results in the detection of those actual faults which may not have been located as a result of investigation of service complaints.

Under corrective maintenance the weak points are not detected until they have actually caused service interruptions, after which the necessary repairs are made.

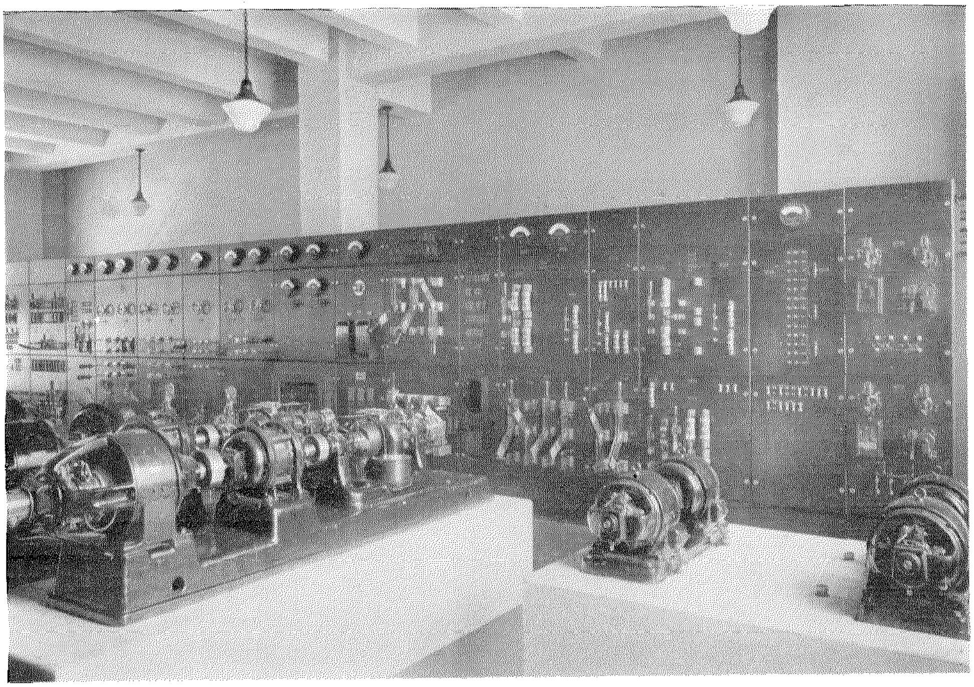
Both systems have been used extensively in telephone operations, and although the adherents to the second system often maintain that for a given class of service the corrective method is more economical, a sufficiently comprehensive study shows that the weak points, or latent imperfections, if allowed to develop, are apt to produce epidemics of troubles and failures which must be immediately attended to, with a resulting unequal load on the personnel. This inefficient use of labor inevitably increases the cost of maintenance, and since the system also involves repairs or replacements which under preventive maintenance might have been corrected by a simple adjustment, the material cost of maintenance increases as well as the labor cost, well illustrating the old adage that "a stitch in time saves nine." While the above comparison is made on the assumption of a given class of service, the highest class of service possible under corrective maintenance cannot approach the quality of service possible with preventive maintenance. The corrective method was the only one used by any of the many telephone companies and administrations in Spain before 1924. The C.T.N.E. adopted from the very beginning the principle of preventive maintenance in all phases of its operations, and especially in the automatic plant, taking full advantage of the routine test circuits with which the 7-A Rotary System is equipped.

The detection of weak points apt to cause failures as well as that of actual troubles, was effected by the joint use of the following five procedures:

(1) Routine tests and systematic inspections;
(2) Concentration tests;
(3) Spot calls;
(4) Investigation of "holdovers";
(5) Service observations.

With the automatic equipment in Spain the routine tests, as has been mentioned, consist in checking the operation of each unit by submitting it to conditions more severe than those of normal service. By this means, the poorly adjusted relays and machines are easily located, as well as poor contacts in the various circuit elements, such as the springs of relays, jacks, and keys, the brushes of selectors, finders, and interruptors, etc., and also any other abnormal circuit conditions which interfere with the satisfactory establishment of a connection. Furthermore, there are certain parts of the equipment which are used infrequently and which therefore would accumulate dirt and dust on their contact surfaces if they were not subjected to the routine tests.

Routine test circuits are installed in all of the different groups of equipment in such a way that each machine in the group may be tested. The test proceeds automatically until a fault is encountered, when the progress of the test stops and an alarm is given. The employee carrying



7-A Rotary Power Equipment, Madrid—Gran Via Exchange out the test, records on an appropriate form the number of the routine and the number of the machine affected and then, after having made the defective machine permanently busy, causes the test to proceed to the next machine. With this procedure it is apparent that routine testing can be carried out with unskilled help, the trained maintenance man being required only for the diagnosis of the trouble and the corresponding repair in the machines reported by the routine test man. The usual arrangement is for the night shift to consist of apprentices for making the routine tests when there is little traffic, while the morning shift contains the trained men able to clear rapidly the faults recorded during the night tests.

The systematic inspections include the adjustment of relays, lubrication and cleaning, and the search for weak connections, loosely mounted apparatus, defective parts, and other mechanical defects which might not be located by routine tests. These inspections, in the larger exchanges, are carried out by mechanics especially trained for this work.

The concentration tests are primarily tests of junctions and are carried out during periods of light traffic. A call is put through over a junction in a certain group, then a second call is placed over the same group without releasing the first call, and this is continued until every junction in the group is occupied and has given indication that it is in a satisfactory condition. Then the calls are released one by one, and care is taken to verify that each release operation is complete.

Spot calls are trial communications set up between different subscribers' lines. The test is performed with two telephones, each telephone being plugged into a subscriber's line circuit at the main frame. The number corresponding to one line is dialed from the telephone connected to the other line, and the employee conducting the trials notes whether or not the connection is properly established, and makes his corresponding record of the number of successful calls and the number of failures.

The 7-A automatic equipments installed in Spain have their registers equipped with a so-called "holdover" circuit, which indicates by a lamp signal the fact that a call has failed through some trouble in the process of selection and, while releasing the calling subscriber, holds the engaged machines until the maintenance man can locate and correct the condition which blocked the call. This feature is valuable in locating faults which develop between routine tests. Faults discovered in this way are definitely located and repaired after having involved the loss of only one call, and that with a minimum of delay to the subscriber.

Service observations are made by connecting a listening circuit and also an impulse recorder, to subscribers' line circuits or to first line finders. The observer is advised by a lamp signal when a call appears on any one of the circuits connected to the observation desk, and, after throwing a key to connect the listening circuit and impulse recorder to the corresponding circuit, makes a record of the time required for the reception of dial tone, the number dialed, the time required for the reception of the busy or ringing tone, the time taken by the called subscriber in answering, and the length of the conversation. If the selection is not completed, if the line is busy, or if the called subscriber does not answer, the observer gives a mechanic the called number, the circuit or junction number under observation, and the reason for the non-completion of the call, and proceeds to observe another call. The circuits connected to the test desk for observation are, of course, changed periodically. Service observation, besides bringing to light any faults which prevent an observed call from being completed, is the best method of obtaining a picture of the quality of service being rendered.

With these foundations, namely, a trained personnel and the five test procedures which make up a system of preventive maintenance, the Company took over the care and maintenance of its newly installed automatic exchanges, and made plans to carry out the following program:

(a) A daily routine test of each and every apparatus unit in all of its cycles of operation (two for first line finders, second and third group selectors and finals, four for connecting circuits, and eleven for registers);
(b) Continuous attention to all register holdovers;
(c) Checking of interoffice junctions every two hours;
(d) 100 spot calls daily in each exchange;

7-B Rotary Automatic Equipment—Palma de Mallorca

(e) Daily service observation of 200 calls;

(f) Systematic inspection organized to insure the cleaning of each unit every two months, and the checking of adjustment of each unit against the manufacturer's specifications every three months or every six months depending upon the apparatus.

All faults encountered were recorded on specially prepared forms which were later analyzed, and a study of these analyses over a certain period of time led to the conclusion that it was neither necessary nor advisable to carry out the routine tests daily for each machine in each of its phases of operation. Likewise an analysis of the results of the systematic inspections showed that it was not necessary to carry out the checking of the apparatus with the frequency previously established, and that the cleaning of the machines need not be effected as often as specified. In view of these conclusions, corroborated by service observations and an analysis of that part of complaints due to equipment failures, the maintenance program of the automatic exchanges was revised to allow a greater length of time between successive cleanings, routine tests, and systematic inspections.

The analyses of the troubles found in routine tests and register holdovers brought out the necessity for two important measures, viz.,

(a) To keep after the mechanics in an effort to combat their tendency to attribute the majority of faults to a few favored causes.

(b) To catalog those particular types of trouble which occurred with too great frequency in order to make a special study of them and get at the root of the trouble.

In connection with the first of these, it is interesting to note that from a certain exchange in Barcelona, where a suspiciously large proportion of the faults was attributed to certain specific elements of apparatus, the entire staff of mechanics was transferred to another exchange and the reports from this exchange began to show a preponderance of faults of the type which previously appeared in the reports from the first exchange. In order to cure the mechanics of a propensity to assign faults erroneously, a few machines of each type in some of the Madrid exchanges were very carefully adjusted, equipped with traffic meters, and then sealed. The maintenance personnel was instructed upon encountering a fault in one of these sealed machines to notify the maintenance supervisor without making any attempt to correct the fault. The results of this experiment appear in the following table:

Troubles Occurring in the Sealed Apparatus in The Delicias Exchange During the Thirteen Months from November, 1928 to December, 1929

Circuit	Number of Machines Sealed	Communications Handled	Number of Faults
Register	2	660,971	13
First Selectors	2	126,473	1
2nd Selectors (local)	2	262,929	1
2nd Selectors (incoming)	2	111,679	1
3rd Selectors	2	159,583	2
Final Selectors	2	61,167	1

These tests produced three excellent effects:

(a) They emphasized the value of preventive maintenance by showing the excellent results that can be obtained by carefully and skilfully made adjustments.

(b) They demonstrated to the mechanics the high quality and efficiency of the equipment.

(c) They consequently dispelled in the mechanics a tendency toward laxity and indifference, a phenomenon which might be called "maintenance sickness"; in other words, a slow and steady decay of morale caused by repeated faults which, because they are not conscientiously and permanently corrected, gradually come to be considered as inevitable and inherent in the system.

Continuing along these lines, and in view of the results obtained, there was prepared in 1930, with the aid of engineers from the International Telephone and Telegraph Corporation, a tentative frequency schedule for routine tests with longer intervals between successive tests on the same equipment. This schedule, with a careful distribution of the work through the month, was used for a trial period of six months in six representative exchanges, two chosen from areas containing four central offices, two from those containing two offices, and two from single office cities. In making these choices as representative as possible, the condition of the equipment, the capacity of the exchange and the geographical location were kept in mind. The importance of the latter is due to the fact that in Spain there is much more dust in the southern towns than in those of the north, and the humidity is greater in the northern towns than in those of the south. The exchanges chosen and the capacities at that time were: the Gran Vía office in Madrid (10,000 lines) and Arenas in Barcelona (6,000 lines), both four-office areas; Valencia (5,000 lines) and Bilbao (7,000 lines) from two-office areas; and Córdoba (2,000 lines) and Vigo (2,000 lines) from single-office areas.

Included in the instructions to the maintenance staff was an order to record, along with the results of each test, the number of machines tested and the total time required for the test. Also with each fault recorded was to be noted the time required in locating the trouble and the time used in correcting it. Every month the reports from the above mentioned six exchanges were examined and analyzed, and compared with reports from similar exchanges operating under the old frequency schedules.

During the first month spot calls and service observations showed that in the six exchanges where the new schedules were in effect, the quality of the service had not decreased but had continued at the same level as in the previous months, and an analysis of the faults encountered in routine tests did not show any increase, nor was any increase noted in the number of register holdovers. Thus it was immediately demonstrated that the frequency of the tests could be diminished without increasing the number of latent troubles. In the following months, as the analyses were continued, they brought out and consistently confirmed the important fact that the total number of faults in a given period of time was actually less when the frequencies of routine tests and systematic inspections were decreased. Part of this phenomenon may be explained by the fact that the repairs were perhaps being made with more care and precision in the six exchanges under experiment, but the important conclusion was that, in making adjustments, checking conditions, and carrying out tests, the mechanics were actually producing faults or maladjustments in the same or other parts of the equipment, and that, therefore, the less often the equipment was touched, within the limits of maintaining satisfactory service, the fewer the faults encountered. After the analyses of the results in these six exchanges had continued for six months, consistently confirming in each of them the above conclusion, the decision was made to economize on labor and material costs by radically reducing the frequency of tests and inspections.

In order to arrive at the extent to which this reduction could be carried, standards or bogeys were established fixing:

(a) The trouble expectancy for each type of circuit or machine per routine test;

(b) The number of register holdovers per day permissible in each class of exchange.

In keeping with these standards, new frequency schedules for the routine tests and systematic inspections were worked out for each class of central office, and after these were introduced the effect on the service was checked by means of service observations and spot calls. The application of the new frequencies to the six exchanges mentioned above resulted in the following reductions in time spent on routine tests:

Exchange	Hours per Month Spent on Routine Tests, Before and After the Change in Schedules									
	Daily Routine		Weekly Routine		Semi-monthly Routine		Monthly Routine		Total for Month	
	Before	After	Before	After	Before	After	Before	After	Before	After
Madrid, Gran Vía	740	15	—	80	—	5	—	25	740	125
Barcelona, Arenas	438	7	—	26	—	2	—	15	438	50
Valencia	350	6	—	16	—	2	—	13	350	37
Bilbao	531	9	—	32	—	3	—	19	531	63
Córdoba	81	2	—	6	—	0.6	—	3	81	11.6
Vigo	96	3	—	7	—	0.7	—	3	96	13.7

During the six month period of trial for the new schedules, inspectors from Madrid visited the exchanges and studied the time necessary for carrying out each phase or cycle of each test, and the time required in locating troubles and in correcting them. The time figures reported for these operations in the six offices were averaged and the resulting figures were used as unit or standard values, some of which are indicated below:

Machines	Simple Test		Complete Test	
	Number of Operations	Unit Time	Number of Operations	Unit Time
First Line Finders	63,744	6″	31,872	12″
Connecting Circuits	200,376	7″	50,049	28″
Registers	99,900	12″	13,320	100″
Local 2nd Selectors	32,640	4″	8,160	10″
Incoming 2nd Selectors	32,520	10″	8,130	23″
Third Selectors	79,920	4″	19,980	10″
Final Selectors	105,600	10″	26,400	23″

In collaboration with engineers from the International Telephone and Telegraph Corporation, these unit time values, together with proper allowances for miscellaneous maintenance duties, sick leave, vacation leave, etc., were applied to the new frequency schedules in order to calculate the personnel required to carry out the new maintenance procedure. The result in reduction of personnel in the six offices under special observation is indicated below:

Exchange	Old Organization	New Organization	Reduction
	Number of Employees	Number of Employees	
Madrid, Gran Vía	23	11	12
Barcelona, Arenas	13	7	6
Valencia	15	8	7
Bilbao	17	9	8
Córdoba	3	2	1
Vigo	3	2	1

The new organization was then extended to all the remaining 7-A Rotary Automatic exchanges in Spain with a corresponding economy in personnel and a notable improvement in the quality and uniformity of the service in all offices.

With this practical demonstration of the efficiency of the new maintenance plan, the engineers of the International Telephone and telegraph Corporation proceeded to incorporate it into a system instruction published as "Rotary Automatic Central Office Maintenance Practices."

As a measure of the efficiency of the work of the central office equipment maintenance personnel and to provide a just basis of comparison of efficiency between the various central offices, there was adopted by the International System a method of evaluating in 10-hour work units the normal time required to maintain any given central office. A figure or coefficient was established for each type of equipment representing the time required (expressed as a fraction of 10 hours) to maintain one unit of that equipment over a period of three months. Thus the total time, expressed in 10-hour units, required to maintain any given central office for three months is the sum of the products obtained by multiplying the equivalent time values or coefficients for each type of equipment by the respective number of machines or elements of that type in the office. The number of employee hours actually expended in the maintenance of a central office for three months, divided by the normal time required, as measured in 10-hour work units, gives an index of efficiency which is expressed as the number of employee hours expended in accomplishing maintenance work which should normally require 10 hours. As this system of measuring maintenance effort takes into consideration the actual equipment installed in each central office, it is evident that, as a basis of comparison, it is much more accurate and satisfactory than those based on "men per thousand lines" or "man-hours per line per year," as neither of these latter plans takes into consideration or makes allowance for the "traffic size" of an office, or whether it includes automatic toll switching apparatus, interoffice trunk circuits, message registers, or other miscellaneous equipment.

The efficiency of the central office maintenance forces in typical offices and for the C.T.N.E. as a whole for the first quarter of 1936 is given below, both as measured by the 10-hour work unit plan and by the number of employees per thousand lines.

Exchange	Average Time Employed in Carrying out the 10-hour Work Unit	Number of Employees per 1,000 Lines
Madrid, Gran Vía	6.97	0.91
Barcelona, Arenas	7.55	0.93
Valencia	8.29	0.88
Bilbao	7.80	1.03
Córdoba	7.54	0.61
Vigo	9.38	0.90
Spain (all 7-A offices)	8.22	0.93
Spain (all 7-B offices)	8.08	0.67
Spain (all Rotary Automatic offices)	8.20	0.90

Early in 1930, coincident with the adoption of the revised maintenance procedure in the 7-A Rotary equipment, the C.T.N.E. adopted, for small single office areas, the 7-B Rotary equipment. In fixing the maintenance practices for these offices, the same procedure as used in the 7-A offices was followed; and, due to the small size and low calling rate of these exchanges, together with the more simple circuit and apparatus units involved, it immediately became apparent that attendance of trained equipment personnel would not be required during the entire 24 hours of the day. Experience in these offices over a 6 year period and with a present total of twenty-two such offices, averaging 1,500 lines capacity each, has shown that one trained maintenance man cannot only take care of the central office equipment, including toll boards, power plant, etc., but also can maintain all associated private branch exchange installations in the exchange area. During the hours when the maintenance man is absent from the central office, all alarm signals are transferred to the toll board, and the toll operating personnel is instructed to call the maintenance man in case of an equipment alarm. In practice it has been found that the maintenance man is called to the office to attend to these alarms on the average of three times per year per office.

The end of 1935 marked for the C.T.N.E. the completion of ten years' experience in the maintenance of Rotary Automatic central office equipment. As has been shown, this experience was divided into three periods: first, the theoretical and practical training of inexperienced personnel for the maintenance of a rapidly increasing number of Rotary Automatic offices; second, the careful and systematic development of exact data on results both as to service and costs, and the development from this data of exact and adequate procedures; and third, the carefully supervised application of these procedures in a constantly increasing number of central offices, which reached a total of forty-eight at the end of 1935. The results have been satisfactory not only to the Company as regards cost, but also to the telephone using public as regards service, as indicated by the fact that less than 0.5% of all calls placed in these exchanges are unsuccessful due to failure in the equipment.

"Micro-Ray Communication," by Messrs. W. L. McPherson and E. H. Ullrich, the paper published in abstract form in the April, 1936 issue of *Electrical Communication*, has been awarded the Institution Premium—the highest award a paper can receive from The Institution of Electrical Engineers. This paper was read before the Institution on January 30, 1936 and has been published in full in the June, 1936 issue of The Journal of the Institution of Electrical Engineers.

The 7-A.2 Private Automatic Branch Exchange in a Government Building at The Hague

By IR. A. J. EHNLE, E.I., and IR. M. J. M. VAN GASTEL, E.I.
Municipal Telephone Administration, The Hague, Holland

General

THE building, situated 30, Bezuidenhout, The Hague, to-day lodges three ministerial departments: the Ministry of Agriculture and Fishery, the Ministry of Commerce, Industries and Navigation, and the Ministry of Social Affairs. It is important that a community of such a size should have a reliable telephone installation capable of carrying a heavy load and giving to its extensions as many facilities as are consistent with simple attendant's service and easy maintenance. This is the reason why, for handling incoming and toll calls, choice was made of the "old fashioned" plug and jack type of switchboard with a multiple field containing jacks which are individually connected to all subscribers by fixed wires.

The automatic P.B.X. was developed by the Bell Telephone Manufacturing Company, Antwerp, at the request of The Hague Municipality, on the basis of the 7-B junction diagram but equipped with 7-A.2 group selectors and final selectors (300 points) and 200 point finders. This system was chosen because it combines the advantages of simple, straight-on connections which are in the highest degree independent of bypaths, and of normal gear driven apparatus, well known by the maintenance people.

Call-back facility by means of a push button, earthing one of the two wires of the telephone set, is introduced. Automatic transfer by means of this push button is not accepted, but transfer of incoming and outgoing city connections is possible, in an easy way, with the help of the attendant, as described later.

The P.A.B.X. has an attendants' board consisting of two positions. The new automatic installation replaces four separate manual boards with a total of six attendants' positions. These latter boards were so loaded with city calls that satisfactory local service was practically impossible. As a consequence the automatisation caused a very considerable increase of local traffic.

The installation of the P.A.B.X. was carried out by the installation department of The Hague Municipal Telephone Administration. The cutover took place on March 14, 1936 and the service, since rendered by the P.A.B.X., has been very satisfactory.

Facilities and Method of Operation

Local calls are obtained by dialing a 3-digit number (a 4-digit number in the future, see level numbering scheme) after receipt of the local dialing tone (quickly interrupted tone). The standard busy and ringing tones are given. The connection, when completed, is under the control of the calling party but, if desired, delayed back-release can be introduced.

Calls to the attendants' board are made by dialing the single digit "1" or "9," which gives access to two separate groups of attendants' lines. The instructions for the attendants are such that calls, for which "9" has been dialed, have preference in being answered. Only a restricted number of subscribers is authorized to dial "9," whereas digit "1" is intended for general use.

False calls and wrong number calls are directed to the attendants' board. For signaling false calls, a delay of approximately 25 seconds is introduced.

The city service is arranged on the basis of "automatic out" and "attended in."

An outgoing city call is originated by dialing "0" after receipt of local dialing tone. When the city dialing tone is received, the number of the wanted city subscriber is dialed. Should all the outgoing city lines be busy at the moment "0" is dialed, continuous hunting takes place until a line becomes free or the local party gives up the call. Any local station may be debarred from originating outgoing city connections. If on such a station "0" is dialed, the local dialing tone is immediately reconnected to the line, indicating that no city connections can be made.

Incoming city and toll calls are signaled on the attendants' board and are extended to the wanted local party by means of a cord plugged into the local subscriber's multiple jack. Means are provided for offering a city call on an existing connection and breaking down this connection if it is a local one. City connections cannot be broken down.

On all city and toll connections call-back facilities are provided. For calling back, the P.A.B.X. subscriber depresses the push button on his set and, on receipt of the local dialing tone, dials the number of the wanted local party, after which the connection is established in the usual manner. Meanwhile the city line is held busy. In order to return to the city connection, the P.A.B.X. subscriber again depresses the push button.

The attendant may be called in on any city or toll connection by calling back in the usual way and dialing "1" or "9." According to the requirements, the local party may, after having been answered by the attendant, return to the city connection by depressing the push button, or have the connection transferred by the attendant.

Outgoing calls can be prepared by the attendant and extended to the local subscribers in the same way as is done for incoming calls.

Night service is obtained by switching in-

Government Building, 30, Bezuidenhout, The Hague coming city lines directly to selected extension lines.

Junction Diagram

The junction diagram is shown in Fig. 1. The amount of apparatus shown on the diagram refers to the present (initial) capacity. By suitable changes, the diagram may be maintained during all stages including the final stage for a capacity of 1,200 local subscribers.

The calculation of the number of switches is based on the following assumptions:

Calling rate in busy hour	1.5
Subdivision of calls:	
Local calls	65%
Outgoing city calls	30%
Calls to attendants' board	5%
Average holding time:	
Local calls and calls to attendants' board	100 seconds
Outgoing city calls	150 seconds

Traffic handled via the attendants' board is twice the automatic outgoing traffic.

10% of the total time for city connections is used for calling back.

On the line finder side, the subscriber lines (call-back lines included) are divided in groups of maximum 200 in accordance with the use of 200 point line finders. On the final selector side, the subscriber lines are divided into groups of maximum 300 in accordance with the capacity and the numbering scheme of the final selector.

The subscriber lines are multipled to the attendants' board and equipped with multiple jacks.

One common group of registers is provided.

In the present stage, two (incomplete) line finder groups and one final selector group are used.

Local calls are handled via a group selector level and a final selector.

Two other group selector levels are used for calls to the attendants' board (single digits "1" and "9"), and one level is used for false calls and wrong number calls. These lines are jack-ended and are provided with calling lamps.

Provision has been made for using one group selector level for tie line service to other P.A.B.X.'s in case it should be required in the future.

The city traffic is handled via two separate

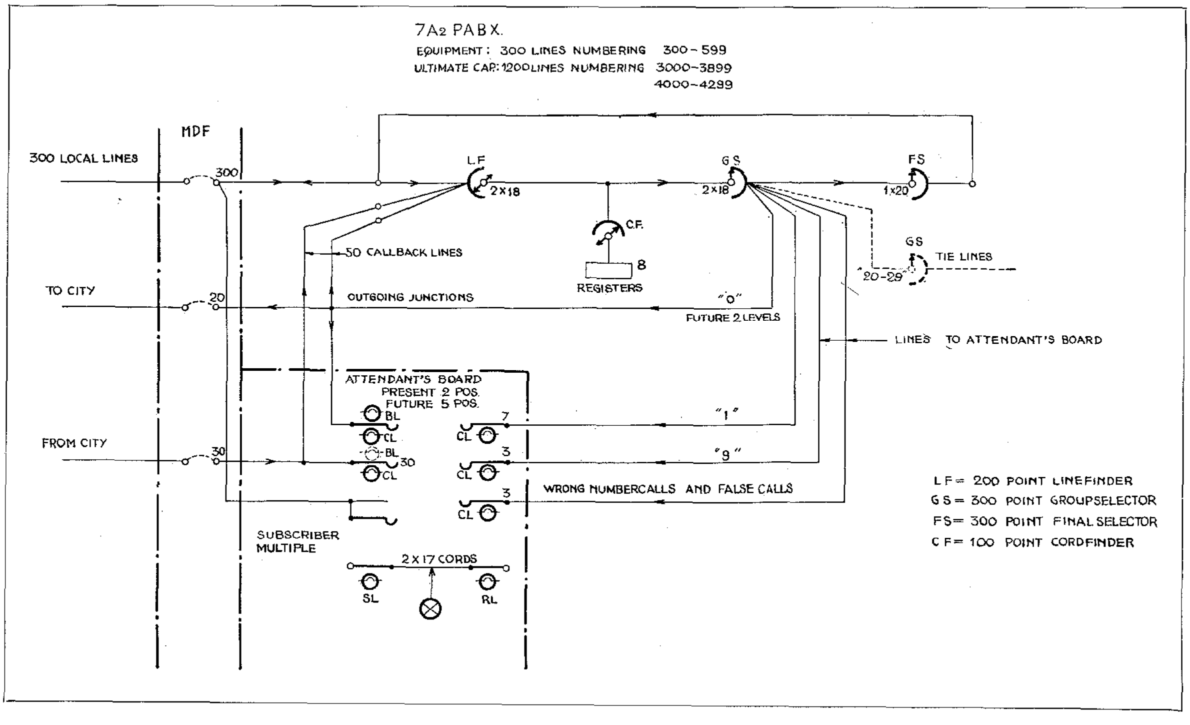


Fig. 1—Junction Diagram for 7-A.2 P.A.B.X.

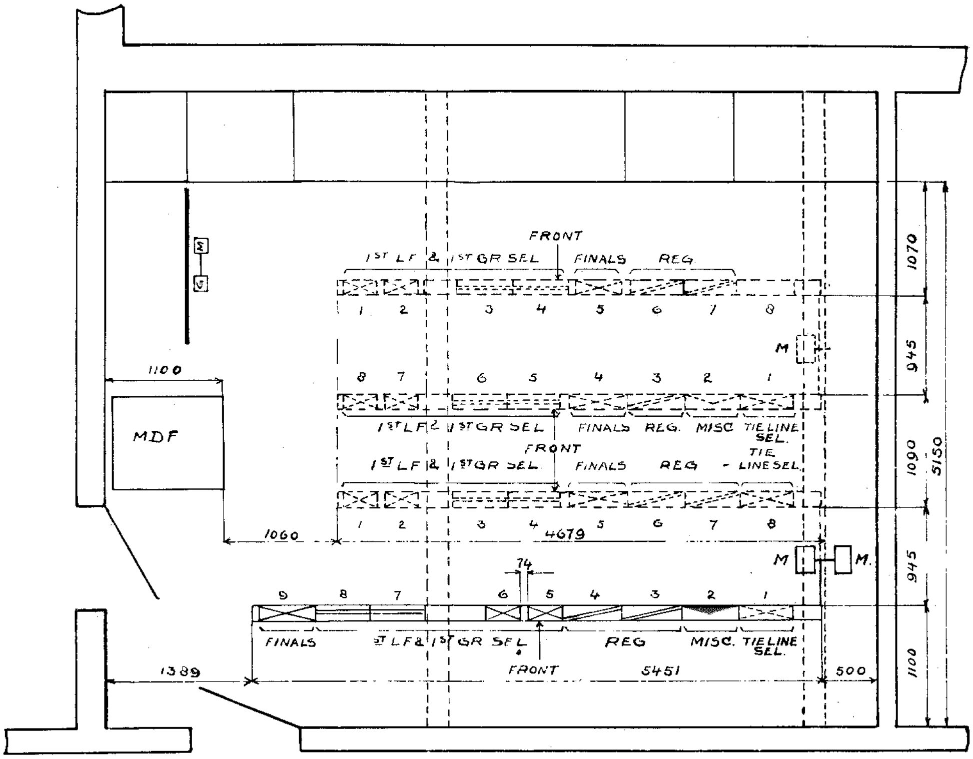


Fig. 2—Floor Plan of Switching Room

groups of lines, one group for outgoing, and the second group for incoming calls.

Outgoing lines are reached automatically (dialing "0") via a level of the group selector or manually via jacks on the attendants' board. Provision is made for double level hunting, a feature which will be used when the number of outgoing lines exceeds the capacity of one group selector level.

Incoming lines terminate on the attendants' board and are each equipped with a jack, a calling and a busy lamp.

For extending city calls and for answering purposes, use is made of one standard type of attendants' cord provided with a three position key (normal, answering, and ringing) and two supervisory lamps.

For both kinds of city lines, Fig. 2 shows the call-back lines to the line finder arcs over which call-back connections are set up. A call-back to a P.A.B.X. party is completed in the same way as a regular call. On a call-back to the attendant, the call-back line transmits an indication from the register back to the city line, with the result that a signal is given to the attendant to enter the connection.

In the case of a call-back signal on an incoming city connection, the operator enters the connection by depressing the key associated with the corresponding cord.

In the case of an automatic outgoing city connection, the call-back signal is given by means of the calling lamp of the outgoing line, and the operator enters the connection by plugging a cord in the corresponding jack. By means of the cord, the connection may be transferred from the originating to a second party.

Numbering Scheme

As previously mentioned, six group selector levels are intended for special purposes and four levels may be used for connecting 300-point

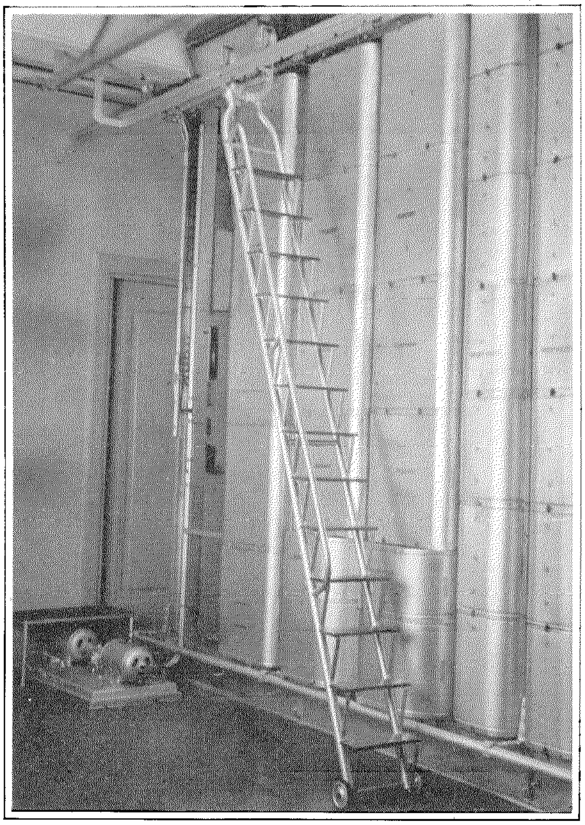


Fig. 3—Part of the Switchrack, Cabling Side

final selectors, giving an ultimate capacity of 1,200 local lines.

For special services single digits 0, 1, and 9 are used (outgoing city connections, normal and preference calls to the attendant, respectively); for tie line calls two digit numbers 20–29 have been reserved.

The local line numbering is as follows:

300 line capacity: 300–599
600 line capacity: 300–899

Beyond this capacity 4-digit numbers will be used:

900 line capacity: 3000–3899
1,200 line capacity: 3000–3899, 4000–4299.

The numbering in the final selector arc is similar to the usual arc numbering except that three instead of two 100-line groups are used.

Automatic Equipment

The automatic equipment for the present 300 line capacity is mounted on seven bays in a single row. The standard switch rack height of 4 meters is used. The length of the rack is 5.45 meters, providing sufficient free space for mounting additional equipment for tie lines, for extension of outgoing city lines, etc.

Two line finder bays are used, each bay comprising the complete equipment for 150 subscriber lines and 25 call-back lines (individual line and cut-off relays, capacity 200 lines) and 18 link circuits (capacity 20), each consisting of a 200 point line finder and two relays, completely wired, but without group selectors.

The two groups of 18 group selectors are mounted on two separate bays.

One final selector bay is used, fully equipped with 20 300-point final selectors, sequence switches, and relay sets.

The registers and cord finders are mounted on two bays, one fully equipped with 5 registers, the second equipped with 3 registers. The cord finders are 100-point 12-brush finders.

Each register comprises a set of relays, a sequence switch, and three step-by-step switches for number registering.

One miscellaneous bay is used, accommodating 20 outgoing city line circuits, the attendant's line circuits, the false call and wrong number circuits, the starting circuits for the switch rack motor, and two sets of slow-speed interruptors with changeover keys and additional apparatus. Space is available for small extensions of the above mentioned circuits.

All outside connections terminate on terminal blocks mounted on the top of the bays and all cabling between the various bays, the main frame, and the attendants' board is soldered to these blocks. For installation purposes, no soldering is required on arcs of machines, a feature which is of particular interest where it is expected that gradually extensions will have to be made.

On the rear side, the bays are provided with the normal 7-A.2 Rotary Automatic System shielding.

The switch rack is driven by a 1/8 hp. duplex motor. Two such motors have been installed, coupled in such a way that only one motor is running. In case of a failure in the a-c. mains supply the driving motor is automatically changed over to d-c. supply.

Four wires per subscriber line are run between the automatic equipment and the main frame, where they terminate on blocks on the horizontal side. On this side each subscriber line is, therefore, represented by four terminals. Three are multipled to the a, b, and c wires, leading to the attendants' board. The fourth terminal corresponds to the "e" terminal of the line finder arc and is grounded for subscribers who are not entitled to originate outgoing city calls.

The floor plan for the present and the future equipment is shown in Fig. 2. The future equipment is shown in dotted lines.

Fig. 3 shows a part of the switch rack (rear side) with the bays for the group selectors, the registers, and cord finders, the miscellaneous bay and the duplex motors.

Fig. 4 gives an idea of the front side of the 100-point cord finders, mounted in the lower part of the register bays.

Attendants' Board

The equipment for the attendants' board consists of the two desk-type attendants' positions (Fig. 5) and two relay racks.

On the upright panel of the desk are located the lamps and jacks for the incoming and outgoing city lines and attendants' lines, the subscribers' multiple jacks, and the general control lamp. Multipling is done in such a way that the complete number of city lines and local lines appears on each pair of adjacent positions.

The left position is further equipped with the night switching keys and lamps. By means of a night switching key, a city line is connected to the local line of a night subscriber, thereby disconnecting this local line from the automatic equipment. The lamp associated with the key lights when the night subscriber's line is in use.

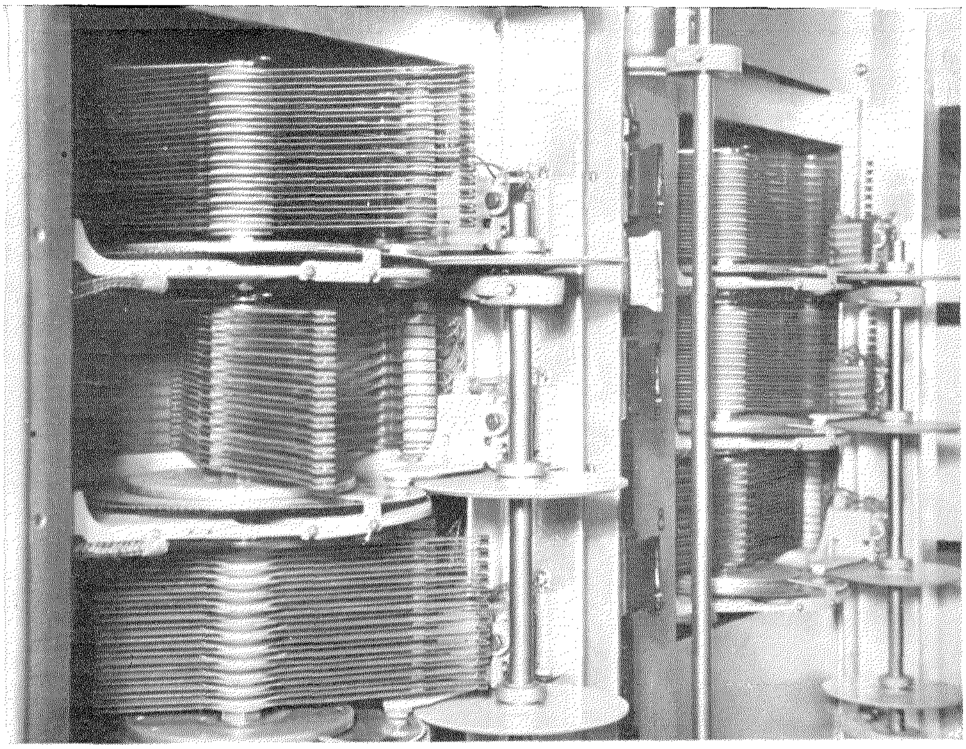


Fig. 4—100-Point Cord Finders

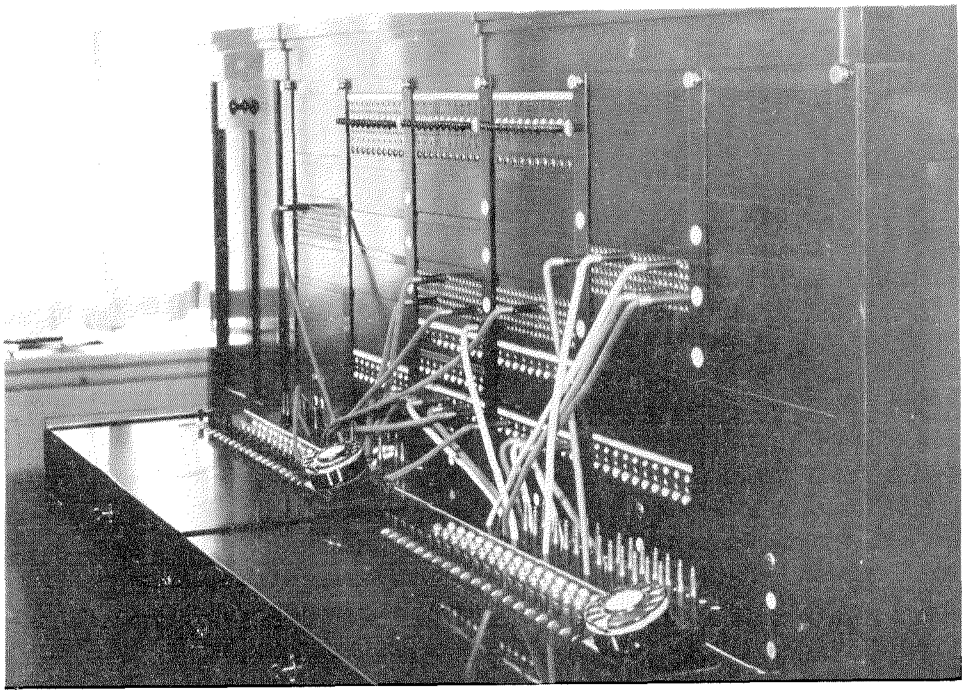


Fig. 5—Two-Position Attendants' Board

The horizontal shelf of the desk comprises keys and lamps for 17 cords. Each cord is provided with two plugs, a combined answering and ringing key, and one green and one white supervisory lamp. The green lamp lights from the time a plug is inserted into a local jack until the called subscriber answers; the white lamp lights at the end of the conversation and flickers when the operator enters into the connection. The answering keys (and the ringing keys) have only one make-contact. Contact faults on the keys are thus reduced to a minimum.

The desk shelf comprises further the position splitting key, the listening key with a listening cord, the buzzer cut-off key and a dial for originating outgoing city connections. The listening cord is provided with a special type of plug, which enables the attendant to offer a call to an existing connection without breaking down the latter.

All other apparatus used in connection with the attendants' board, such as relays, resistances, and condensers, are mounted on the relay racks.

Traffic Observation

In the registers, provision is made for centralized traffic metering, by means of which the number of automatic outgoing calls, calls to the attendants' board, and tie line calls (subdivided in accordance with the tie line numbering), which have been controlled by the registers, are metered separately.

The total number of calls is also registered. Separate registering of local calls can be obtained from the final selectors. Moreover, the usual facilities are provided for the connection of recording ammeters and overflow signaling devices.

Traffic observation has shown that the local traffic increased considerably following the installation of the P.A.B.X. This indicates not only that there was a demand for telephone communication which could not be satisfied with the old equipment, but also that the quick and reliable service, rendered at any time and to any extent by the automatic installation, improves methods of working and results in a saving of time.

In order to give an idea of the traffic handled by the new installation, some traffic data may be of interest. The following data refer to an observation period of one week (39 service hours); but, in addition, the average hour traffic and the busy-hour traffic are given. The busy-hour traffic is based on the experience that one-fifth of the local day traffic is handled in the busy hour.

	Traffic Originated by P.A.B.X. Subscribers		Traffic Handled by Operators	
	Local Calls and Calls to Attendant (call-back included)	Outgoing City Calls	Prepared City Connections and Calls to Toll Recording	Incoming City and Toll Connections
Total of a week	11,500	4,600	1,250	5,070
Average hour	295	118	32	130
Busy hour	414	165	45	182

Call-back connections, which are classed as local connections in the above table, are estimated as occurring on 10% of the total number of city and toll connections, *i.e.*, in the busy hour, 35 call-back connections are made.

Eliminating these connections, the total number of busy-hour calls originated by subscribers is 544, resulting in 1.8 busy-hour calls per subscriber.

Power Plant

The power plant is composed of a 180 ampere hour storage battery, a 2.6 kW three-phase motor generator and the necessary controlling and regulating equipment mounted on a panel which is shown in Fig. 6.

The power plant is operated on the "floating" scheme. By means of the charging machine with regulating device, the battery voltage is maintained at a fixed value, sufficiently above the normal voltage to prevent discharge.

During service hours the charging machine operates continuously and the total load of the installation is carried by the machine except for short current peaks, which are taken care of by the battery. The machine is stopped during the night and, if energy is still required, it is supplied by the battery. This energy loss and also the losses due to the above mentioned current peaks, are gradually replaced during day service.

For voltage regulation use is made of a Brown Boveri automatic quick-acting regulating device, which also includes the necessary automatic apparatus for establishing the connection between the generator and the battery at the proper voltage and for disconnecting the machine in case of reversed current. The device is mounted in a box visible at the centre of the panel.

In addition to the automatic regulating device, the panel comprises some switches and a rheostat by means of which the automatic device can be switched off and replaced by manual charging control.

Dialing tone, busy tone, and ringing current are taken from a small ringing and tone machine. In case of a failure, the tone circuit is automatically changed over to a special buzzer arrangement, whereas ringing current is supplied from the central exchange by means of a cable pair.

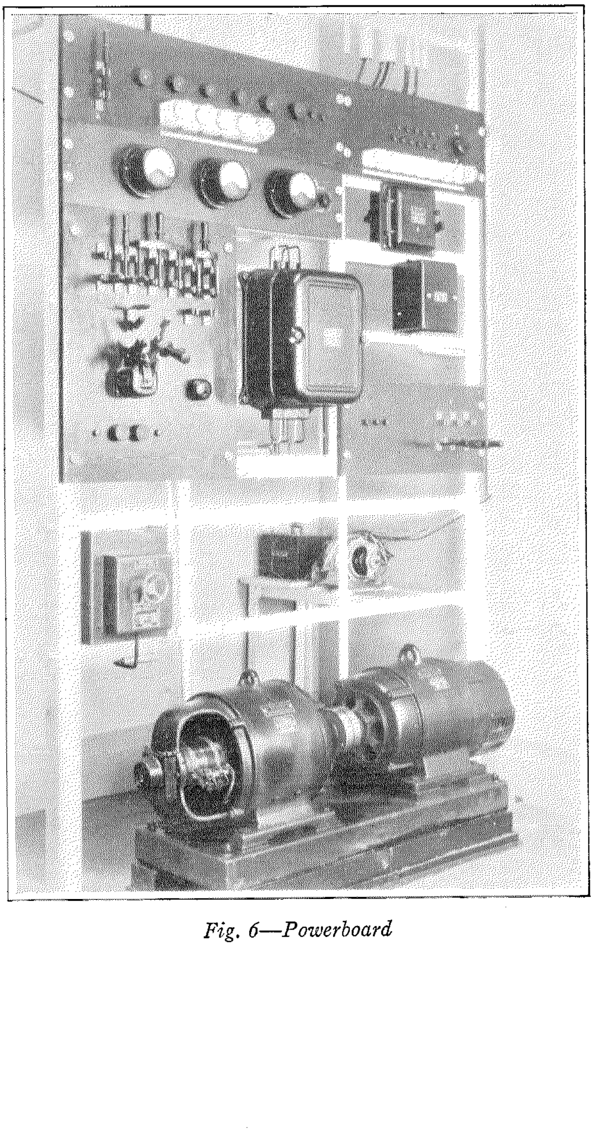


Fig. 6—Powerboard

Permalloys and Related Ferromagnetic Alloys—A Review

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IN recent years, the demands of communication and electrical engineers for ferromagnetic materials have brought into existence a branch of metallurgy concerned with the production of metals and alloys with rigidly controlled magnetic characteristics. The mechanical properties, in these cases, are of relatively minor importance.

Two classes of these ferromagnetic materials may be distinguished. On the one hand there are the permanent magnet alloys, a group of magnetically hard substances, the range of which has lately been extended considerably by the development of the aluminium-nickel-iron alloys. It is not proposed to deal with them in the present paper. Attention will be confined to the second group, consisting of the easily magnetised, magnetically soft materials including the permalloys, perminvars, and related alloys. These are employed whenever it is desired to provide an easy path for the magnetic flux, as in magnetic shields of all kinds, or to increase the inductance of a feebly energised coil or transformer by the use of a ferromagnetic, highly permeable core in which a high magnetic flux density is readily built up. The use of nickel alloys for this purpose dates from G. W. Elmen's discovery of the nickel-iron alloy called permalloy, the first patent for which was filed in the United States of America in 1916. This event had a profound influence on the study of ferromagnetism, and led the way to the development and intensive study of a numerous series of related alloys. This work has been carried out in America in the Bell Telephone, the General Electric, and the Westinghouse Laboratories; in Germany in the laboratories of the Siemens and Halske and Allgemeine Elektricitaets-Gesellschaft; as well as elsewhere.

The essential characteristics of this group of alloys are the very high values of magnetic permeability at low values of magnetising fields (*H*) and the almost negligible magnetic hysteresis which they exhibit when they are properly heat treated. To illustrate these features, typical magnetisation and hysteresis curves for silicon steel and a modern nickel-iron alloy, permalloy *C*, are given in Figs. 1 and 2, and the derived permeability curves for the same materials, in Fig. 3. The remarkable degree to which the permalloy is magnetised at the low values of *H* is clearly shown, as well as the manner in which it responds with very little hysteresis lag to small changes in magnetising field. The two properties are largely interconnected, and it is generally safe to assume (though there are some well recognised exceptions) that the higher the permeability at low fields, the lower is the hysteresis loss.

It may be advisable, incidentally, to make it clear at this stage that these materials do not retain their magnetic superiority when placed in strong magnetic fields. Under these conditions, when magnetic saturation is approached, they will not carry so high a density of magnetic flux as pure iron. They make less powerful electromagnets and find no application in the manufacture of armatures and pole-pieces of heavy current electric motors, generators, and similar equipment.

The distinction between the behaviour of magnetic materials at high and low flux densities is important. At low flux densities, where high values of permeability are a measure of the readiness of the material to respond to feeble magnetic impulses, the behaviour of all materials is very considerably modified by mechanical stressing, by the presence of small amounts of impurities, and by previous heat treatment. These external factors, however, only affect the early speed of response of the material, and have little or no effect at all on the final value of flux which it can carry at saturation. This is a function of the chemical composition alone; and values for some representative materials are given below:

	Intensity of Magnetisation at Saturation: $(B-H)$ at $H \rightarrow \infty$
50 : 50 Iron-cobalt alloy	24,000 gausses
Iron	22,000 "
45 : 55 Nickel-iron alloy	16,000 "
78.5 : 21.5 Nickel-iron alloy	10,700 "
3.8 : 78.5 : 17.7 Molybdenum-nickel-iron alloy	8,500 "
Nickel	6,150 "

The curves shown in Figs. 1 and 2 present most of the purely magnetic characteristics of the materials. In utilising these alloys it is generally only necessary to concentrate attention on a few special features of these curves, but such additional factors as the electrical resistivity of the alloys and the dimensions, particularly the thickness, of the magnetic structure, must also on occasions be taken into account. The most important of these characteristics are set forth below:

Important Characteristics of High Permeability Alloys

A. Purely magnetic characteristics	*B*. Complex characteristics, involving electrical resistivity and specimen dimensions, in addition to magnetic properties.
Initial Permeability	Effective a-c. initial permeability at specified frequencies.
Maximum Permeability	Effective a-c. initial permeability with superimposed steady field.
Hysteresis loss	Total energy loss at specified frequencies.

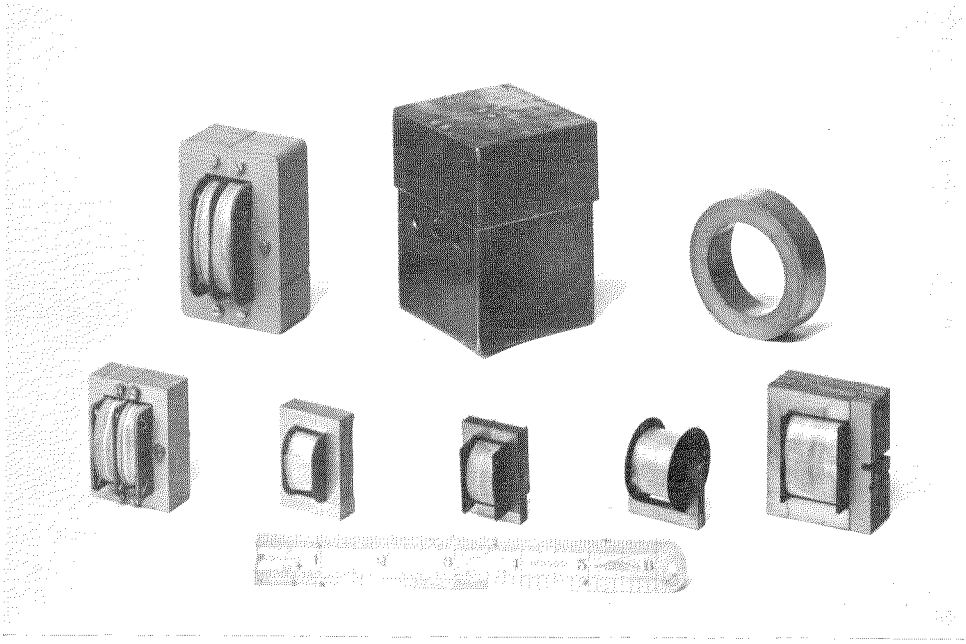
Determinations of the purely magnetic characteristics are usually carried out by ballistic measurements on a core built up from a number of annular ring stampings or else wound from narrow tape in the form of an annular coil. In some instances, annular rings machined from the solid metal have been used, and yield comparable results provided that the heat treatment applied does not involve such rapid rates of cooling as to introduce a mass effect.

In preparing ring stampings, the width of the ring should be as small as possible, in order to avoid errors due to a non-uniform distribution of flux, but otherwise the dimensions are without influence on the observed results. It should, however, be noted that if the alloys have directional properties—imparted as a result of the rolling operations or otherwise—these can only be detected by tests on tape cores.

Since, in service, the alloys usually are subjected to alternating magnetic fields, direct measurements of effective permeability under operating conditions are very desirable. If the alternating field is of small magnitude with the frequency not above 100 to 200 cycles per second, and the sample is made from sheet not thicker than about 0.015 inch, the effective permeability is very nearly identical with the ballistically-determined initial permeability. Measurement of a-c. permeability, using suitable bridge circuits, is, indeed, the simplest method of measuring initial permeability and is usually the most accurate since, even with the most sensitive galvanometers, the ballistic method is difficult to apply at very low fields. At higher frequencies when thicker specimens are under test, or when the amplitude of the alternating field is considerable, a form of "skin effect" is set up through the action of eddy currents and hysteresis effects in the material, and the value of effective permeability may be much lower than the true permeability obtained by ballistic methods.

The losses under these conditions are reduced by any factor which increases the resistance of the material. The use of very thin stampings, insulated from one another, thus often enables higher effective permeabilities to be obtained. For the same reason, it is desirable that the alloys should have as high a resistivity as possible. The effect of these factors can, of course, be calculated by the recognised formulæ with a very fair degree of precision.

One further factor which needs to be considered in certain cases cannot, however, be calculated, and it is necessary to make tests on each type of material to determine its influence. This is the action on the a-c. permeability of a superimposed steady field, such as may be produced by a direct current flowing in the windings of a transformer. The result is broadly to reduce the a-c. permeability very considerably, but the effect is complicated and the previous history of the sample needs to be considered (due to hysteresis effects).



Typical Applications of Permalloy for the Cores of Audio Frequency and Instrument Transformers and also as a Magnetic Shield

In making measurements of high precision during laboratory investigations on these high permeability alloys, the greatest difficulty which is encountered is that of making sure that the specimen is entirely free from stress. The alloys differ to some extent in their sensitivity to applied stresses; and, of their magnetic characteristics, it is the initial permeability which is most susceptible to the effects of small stresses. If, therefore, accurately reproducible results are to be obtained, every precaution must be taken to avoid stresses of any kind in the material. An obvious precaution against stressing while testing is to place the sample in a wooden, bakelite, or hard rubber thin walled container, over which the coil winding is applied. It is equally important, however, to avoid stresses being set up by adjacent layers of a coil or adjacent stampings in a pile sticking to one another during heat treatment. If this occurs, it is impossible to obtain reliable results. Several methods of prevention are available. Stampings may be interleaved with oxidised silicon steel stampings, or the surface of the alloy may be coated with some such substance as graphite, oil, paper, or a suspension of kieselguhr in water or carbon tetrachloride. It is always advisable to avoid surface oxidation during heat treatment, since it may give rise to contraction stresses; also, with stampings, to take steps to ensure that they will be as flat as possible after heat treatment.

Trend of Recent Developments

The original permalloys invented by Elmen were binary alloys of nickel and iron which develop high values of initial permeability only after suitable heat treatments.[1] The preferred heat treatment for the binary alloys consists in first annealing at 900° C. in a closed pot, in which the alloy is allowed to cool slowly in the furnace, and then reheating to 600° C. and cooling at a critical rate, usually rather faster than is provided by free suspension in still air. The superiority of this "air quenching" treatment over a simple anneal in developing high values of initial permeability in the range of compositions between about 50 and 85% nickel is illustrated in Fig. 4.[2] On the other hand, it is interesting to note that if the alloys in this region, instead of being cooled rapidly, are given a prolonged "baking" at about 400° C., the initial permeabilities are reduced to very low values.

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[1] For all numbered references, see list at end of paper.

The air quenching treatment, however, is costly and difficult to carry out with certainty as an industrial process. Furthermore, if the parts to be treated are at all massive, it may become impossible to cool every portion throughout the mass at the same rate, and thus to develop in them the best magnetic properties. Another disadvantage of the original alloys is that their electrical resistivity is somewhat low. As a result, the eddy currents which are induced when the alloys are used in fluctuating magnetic fields may appreciably reduce the effective permeability. Finally, it was not to be expected that the binary alloys should possess ideal characteristics for all applications, and it appeared desirable that alloys having special magnetic properties for specific uses should be developed if at all possible.

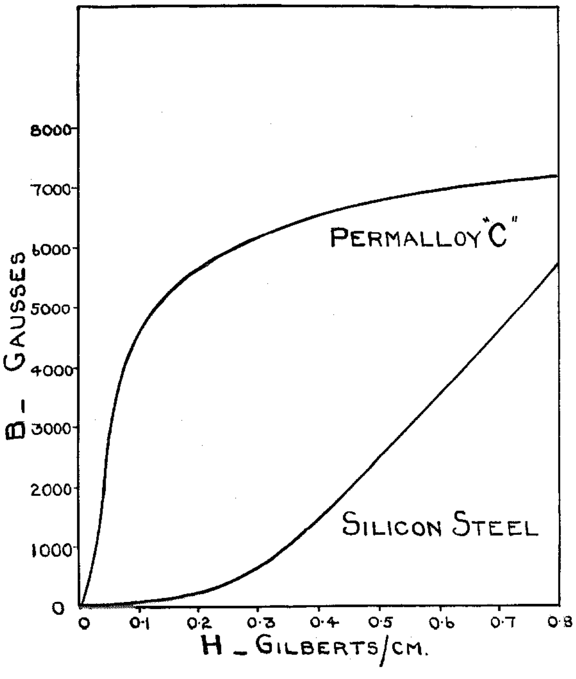


Fig. 1—Magnetisation Curves for Permalloy C and Silicon Steel

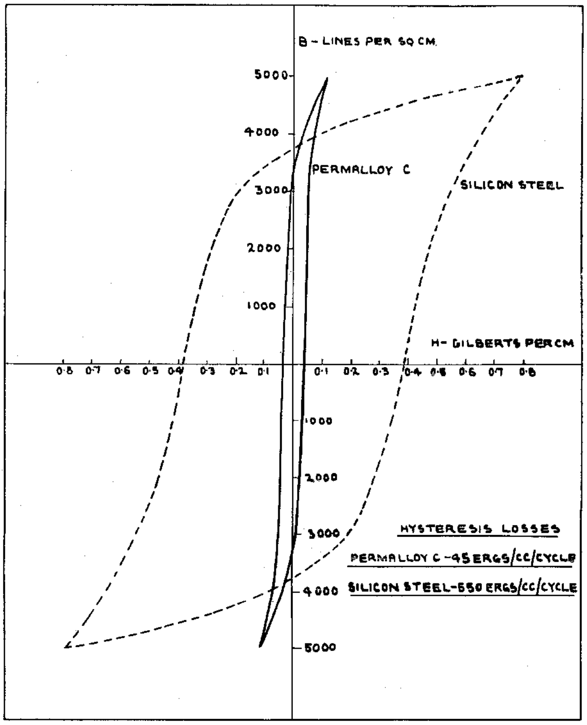


Fig. 2—Hysteresis Curves for Permalloy C and Silicon Steel

The main lines of attack in an endeavour to overcome these difficulties have been along the following directions:

(1) Addition of further alloying elements to the nickel-iron alloys;
(2) Control of crystal (and domain) orientation by magnetic restraint during heat treatment and by cold-working;
(3) Control of purity of the alloys.

Development of Complex Alloys

By far the greater part of the experimental work carried out during the last 15 years has been in the nature of a search for new alloys showing improved or specific characteristics; if possible, after a simple heat treatment. It will be convenient to consider these alloys in two groups:

(1) Alloys having high values of permeability and resistivity, usually after a simple heat treatment;

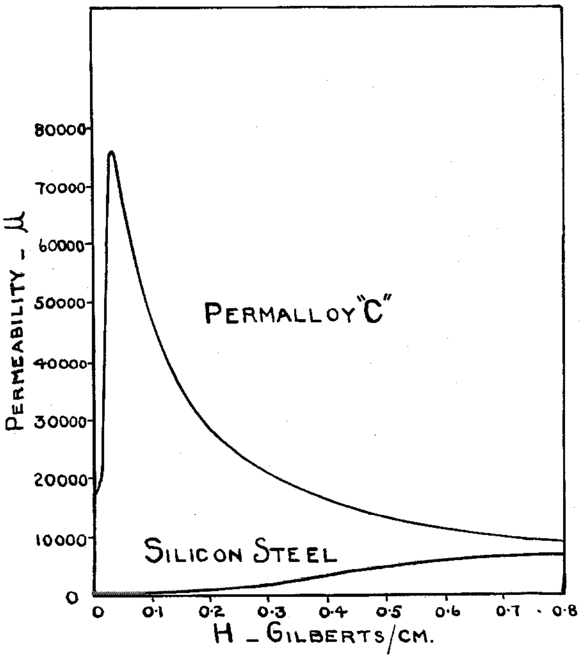


Fig. 3—Permeability Curves for Permalloy C and Silicon Steel

(2) Alloys in which the permeability remains constant from very small up to appreciable values of field strength.

High Permeability Alloys

The most important of the high permeability alloys are those in which a third element (usually molybdenum, chromium, or copper), and sometimes a fourth element is added to a nickel-iron binary alloy. These additions invariably increase the resistivity and often enable very high values of initial permeability to be obtained with a simple heat treatment.

Ternary Alloys of Ni-Fe-Cu, Ni-Fe-Mo, and Ni-Fe-Cr

The only ternary alloy system in this group which has been completely investigated is the nickel-iron-copper series, and unfortunately this is not one which in itself exhibits magnetic properties sufficiently striking to warrant its general commercial use. The exploration of this system has been conducted by Otto von Auwers and Hans Neumann,[4] in the course of which ring stampings 2.36 inches outside diameter, 1.77 inches inside diameter, and 0.014 inch thick were tested by ballistic methods. The values for initial permeability after annealing at 1100° C. in hydrogen, and after a "permalloy" double heat treatment (employing a first anneal at 900° C.) similar to that described above, are shown in Figs. 5 and 6. It will be noticed that the narrow zone of composition in which high values of initial permeability are obtained occupies much the same position, whichever heat treatment is used, and it has been contended that the differences are due more to the different temperatures used for annealing than to the difference in the cooling rates. Thus these alloys represent an advance over the binary nickel-iron alloys in being far less sensitive to heat treatment conditions. With the air quenching treatment, the greatest value observed for initial permeability was 13,500 for a composition of 70% nickel, 13% copper, 17% iron. After annealing at 1100° C., an initial permeability of 12,100 was found for

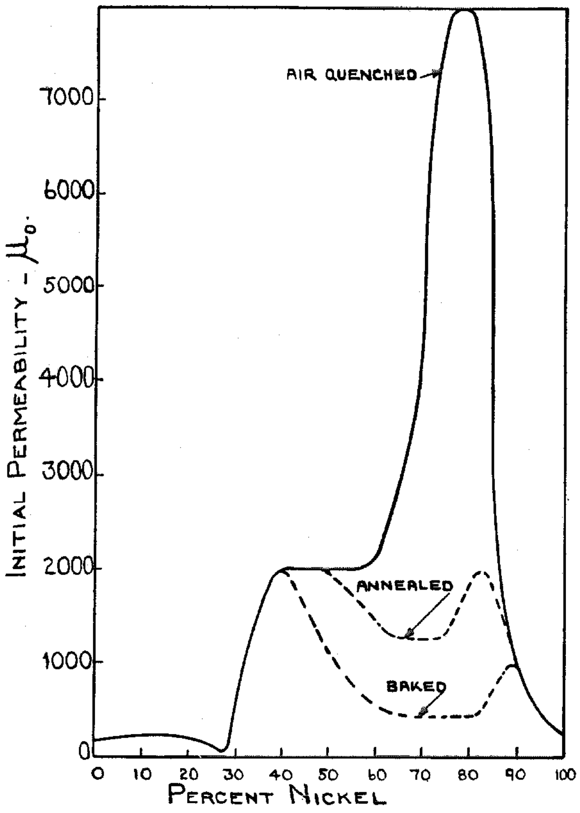


Fig. 4—Effect of Heat Treatment on the Initial Permeability of Iron-Nickel Alloys

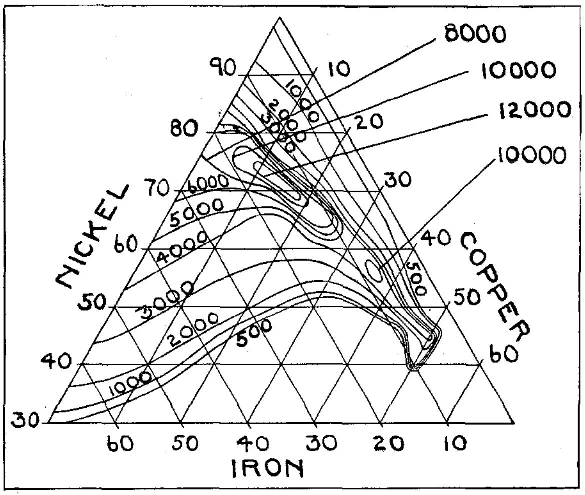


Fig. 5—Values of the Initial Permeability of Alloys in the Nickel-Iron-Copper Series after Air Quenching the Annealed Alloy from 600° C.

a composition of 60% nickel, 28% copper, 12% iron.

Certain of the ternary nickel-iron-molybdenum and nickel-iron-chromium alloys have been used widely in England and America, but for neither of these systems are complete diagrams of their magnetic properties available. It is generally believed that the best magnetic properties are obtained if the nickel content is maintained at about 78.5%, and Figs. 7 and 8 show values of initial permeability with alloys containing this amount of nickel and having up to 10% of iron replaced by molybdenum or chromium.[2, 3] The action of these added elements, which themselves are non-magnetic, in modifying the response of the alloys to heat treatment is very striking.

Small additions increase the permeability obtained after double heat treatment (air quenching) but slightly larger additions enormously increase the permeability found after a simple heat treatment; so much so that, with 3.8% molybdenum, the highest initial permeability (20,000) obtainable by any heat treatment with any of this series of alloys is obtainable. The alloy with 3.8% chromium also has a very high initial permeability (12,000) after annealing and, in addition, has a slightly higher resistivity (Fig. 9).

The curves shown for initial permeability are based on the average results obtained from a large number of tests. It may be advisable here to point out that they should be taken only as indicating the general trend of the relation between initial permeability and composition, and that the values found for any particular sample are liable to vary quite appreciably from the average. Some of the causes for the rather large "scatter" invariably observed in the study of these magnetic materials are discussed later.

Both the 3.8 chromium and 3.8 molybdenum permalloys have found a considerable application on account of the ease with which high initial permeabilities, coupled with high resistivity, are obtained after an annealing treatment at about 1000° C. followed by slow cooling. It should be noted that the magnetic saturation of both of these alloys is low, and that the maximum permeabilities are usually lower than are obtained with the original 78.5% nickel permalloy. Typical values are as follows:

	Intensity of Magnetisation at Saturation: $(B-H)$ max.	Maximum Permeability
3.8 Chromium 78.5 Nickel Permalloy............	8,000 gausses	62,000
3.8 Molybdenum 78.5 Nickel Permalloy......	8,500 "	75,000
78.5 Nickel Permalloy, air quenched............	10,700 "	105,000

More Complex Alloys

In recent years, a number of alloys having four or more constituents have been chosen, more or

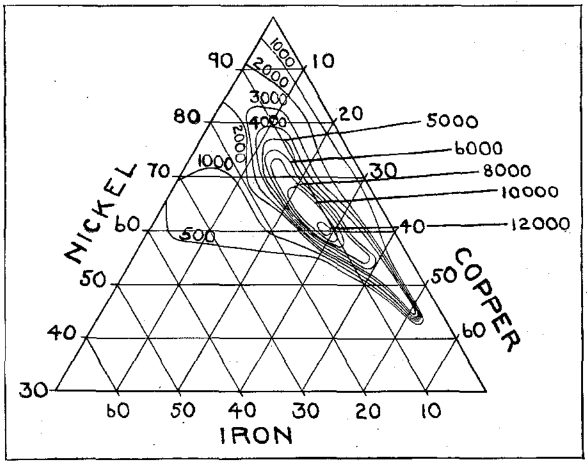


Fig. 6—Values of the Initial Permeability of Alloys in the Nickel-Iron-Copper Series after Slow Cooling from 1100° C.

less arbitrarily, and in some instances exploited commercially. Very high values of initial permeability have been recorded for some of them; as an instance, an initial permeability of 51,000 has been claimed for an alloy of 72% nickel, 11% iron, 14% copper and 3% molybdenum.[4, 5] Whether such a high value is obtainable regularly in production appears doubtful.

Constant Permeability Alloys

For some purposes it is most desirable that the permeability, instead of rising steeply as the field strength is increased, should remain—at least over a limited range—constant in value. Alloys with such characteristics were first deliberately sought in connection with the continuous loading of submarine telephone cables; and when, a few years ago, the project of a transatlantic telephone cable was receiving a large amount of attention, considerable impetus was given to their investigation.

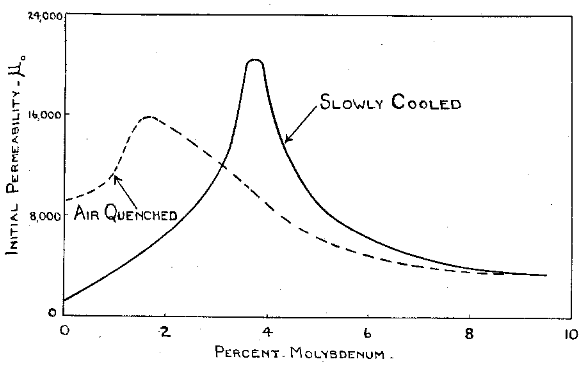


Fig. 7—Effect of Molybdenum Additions on the Initial Permeability of Permalloy Containing 78.5% Nickel

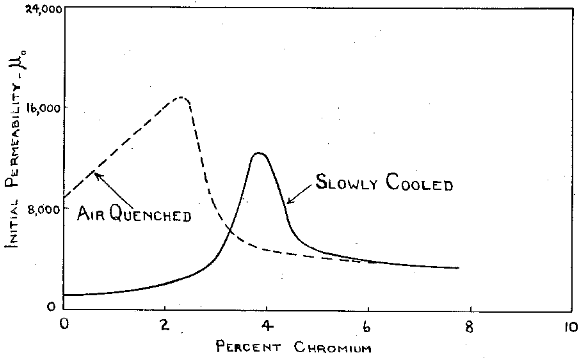


Fig. 8—Effect of Chromium Additions on the Initial Permeability of Permalloy Containing 78.5% Nickel

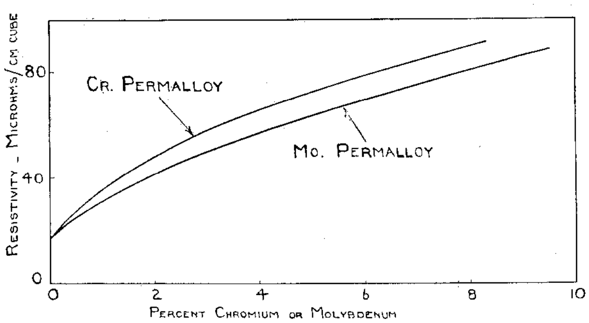


Fig. 9—Effect of Chromium and Molybdenum Additions on the Resistivity of Permalloy Containing 78.5% Nickel

These properties were first observed in the binary nickel-iron alloys containing between 64 and 76% of nickel after the annealed material had been "baked" or given a low-temperature heat treatment at a temperature between 400° and 500° C. for 24 hours or more. It was later found that the effect was very much more pronounced if cobalt were added; and an extensive investigation of the nickel-iron-cobalt series brought to light a range of such alloys, as indicated in Fig. 10, to which the name "Perminvars" was given.[3, 6, 7] All alloys in this range respond to a "baking" treatment by developing the perminvar characteristic of remaining constant in permeability as the field strength is increased from zero up to an appreciable value. A typical alloy, showing these characteristics to a marked degree, is that containing 45% nickel, 25% cobalt, and 30% iron; in Fig. 11, permeability curves for this material after air quenching and baking are given. The baking treatment reduces the initial permeability, but appreciably extends the range over which it remains unaltered. The air quenched alloy has an initial permeability of just over 600, which commences to rise at once when the field is increased, whereas for the baked alloy the initial permeability of 300 remains constant up to a field of over 3 gilberts/cm.

One disadvantage of these alloys is their low resistivity, which is only 18 microhms/cm^3 for the composition quoted, but by replacing about 7% of iron by molybdenum the resistivity is increased to 80 microhms/cm^3. The 7% molybdenum perminvar normally has a rather higher initial permeability than the 45–25–30 perminvar, but it does not remain constant in permeability over so wide a range. The range of constancy can be extended, however, by prolonging the baking period.

In seeking for an explanation for the behaviour of these alloys, it is tempting to suggest that precipitation of a magnetically hard constituent may occur during the baking treatment, the action being similar to the precipitation of a mechanically hard disperse phase in precipitation-hardening alloys such as duralumin. Developing this idea, it has more recently been suggested that the precipitated phase may consist of what is known as a "superlattice."[9, 10, 11, 12] If the alloy is cooled rapidly, the atoms of nickel, iron, and cobalt are arranged at random in the crystal lattice, and in this condition the material is most susceptible to weak magnetic fields. It is suggested that baking may cause the atoms, in some areas of the alloy at least, to arrange themselves in superlattices, in which the atoms of nickel and iron each occupy certain definite fixed positions. The precipitated constituent, whether a disperse phase or a superlattice, is considered to be less easily magnetised than the solid solution formed by more rapid cooling.

It has not thus far been possible to verify either by X-ray or microscopical examination the existence of two phases in the baked alloys. In a recent investigation,[12] no evidence of the existence of a superlattice was, on the contrary, found by X-ray methods in the alloy containing 69% nickel, even after annealing at 447° C. for 1560 hours, and no compounds were detected in the whole range of the nickel-iron alloys. Bimetallic samples having a magnetically hard core of piano wire encased by 78.5% nickel permalloy have, however, been found to approximate very closely to perminvar in their behaviour, which has thus been held to give some support to these ideas.[2]

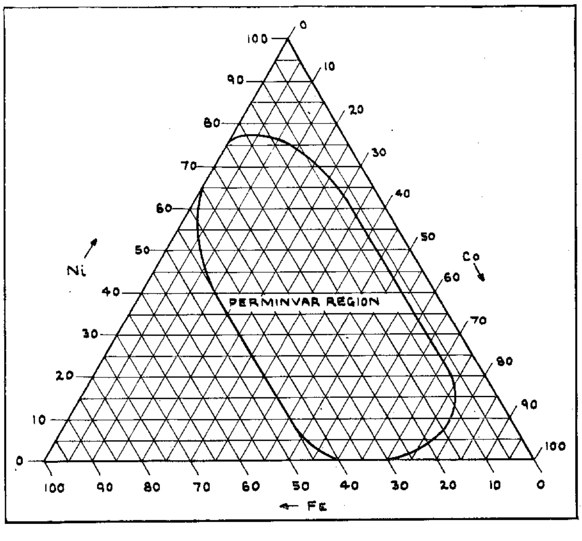


Fig. 10—Diagram Showing the Range of Composition in the Nickel-Iron-Cobalt Series in which the Alloys Show Perminvar Characteristics after a "Baking" Treatment.

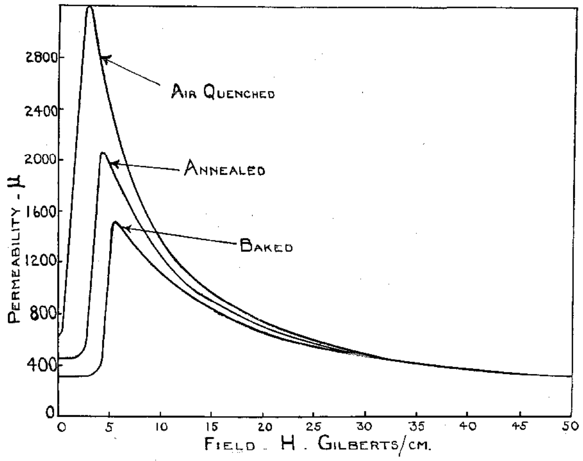
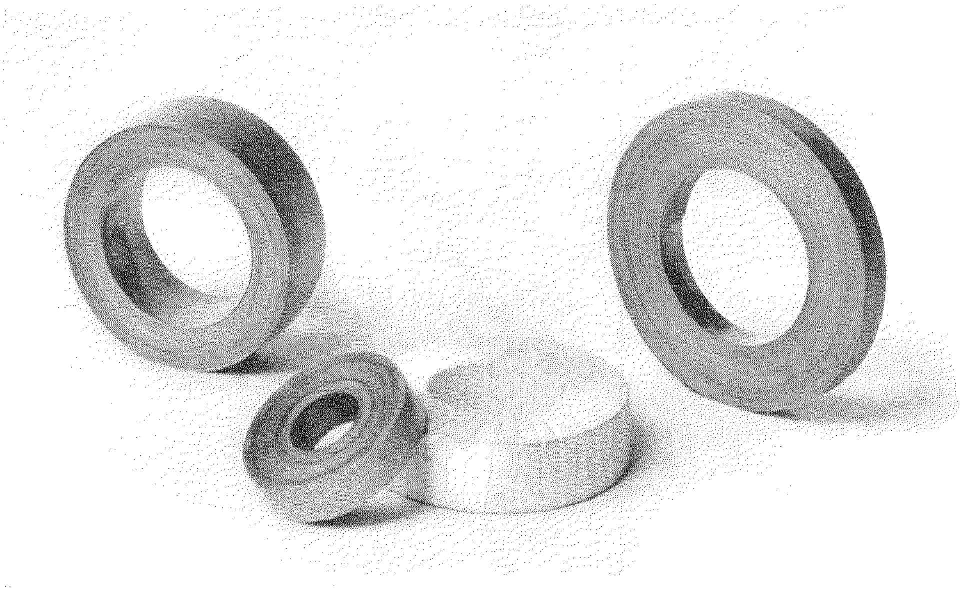


Fig. 11—Effect of Heat Treatment on the Permeability of 45 : 25 : 30 Perminvar

Furthermore, if precipitation of a disperse phase brings about these effects, it might be expected that other metals besides cobalt would form phases which could be precipitated and, in doing so, impart constant permeability characteristics to the nickel-iron alloys. According to the claims of some recent patents,[13] such properties, in fact, are possessed by a number of elements. It is stated that if one of the metals—silver, beryllium, antimony, magnesium, or calcium—is added in amounts up to 3%, it forms solid solutions with the nickel-iron alloy at high temperatures but that on cooling the solubility falls rapidly. By quenching such a ternary alloy from 900° C. or over, there is formed a supersaturated solid solution which on baking at 250–500° C. will precipitate a disperse phase. After this treatment, all these alloys are claimed to exhibit constancy of permeability over an appreciable range. Copper in large amounts will also act as a precipitable element, provided that the nickel content is not over about 80%. In-



Spiral Cores of Permalloy Strip for Instrument Transformers

creased amounts of nickel increase the solubility of copper.

By adding additional elements which are soluble in nickel-iron alloys, it is possible to increase the resistivity. Suitable resistance elements are said to include chromium (soluble up to 15%), molybdenum (up to 12%), manganese (12%), tungsten (10%), aluminium (5%), silicon (5%), vanadium (5%), and cobalt (15%). A typical alloy made according to these principles contains 78.5 parts nickel, 18 parts iron, with 3 parts molybdenum, 2 parts silicon and 1 part manganese as soluble resistance elements, and 1.2 parts beryllium as a precipitable element. After baking a supersaturated solid solution of this alloy for 36 hours at 375° C., precipitation occurs and there is obtainable a permeability of 850, which remains constant up to a field of 0.1 gilbert/cm. The resistivity is 51 microhms/cm^3.

Control of Crystal (and Domain) Orientation

Apart from varying the composition and heat treatment, it is natural that the possibility of influencing magnetic characteristics by control of the microstructure and crystal orientation of these alloys should have been explored. The effect of the most easily controlled variable, crystal size, on the permeability and—more particularly—the hysteresis losses in pure iron and silicon iron sheet has been the subject of much discussion and investigation;[14] and it has been claimed that the losses are reduced as the crystal size increases. The view put forward by Yensen[15] is that the improvement is due to the more regular spacing of the atoms which follows the reduction of boundary area, near which the atomic arrangement is inevitably distorted. On the other hand, the suggestion has been made that material with a large crystal size is often better annealed, possesses less internal stress, and contains fewer inclusions and other impurities than fine grained material; and that it is to these causes that the magnetic improvement which has sometimes been recorded must be attributed. In the light of recent investigations, it seems probable that the mere size of the crystals which make up the alloy has not in itself any appreciable influence on magnetic characteristics. Most of the observations on the effect of crystal size have ignored the important fact that the crystals of many of these materials are themselves anisotropic; that is, that they are more easily magnetised along certain crystal directions than along others. Iron (which has a body-centred cubic lattice at room temperatures) is, for example, magnetised nearly to saturation by a field of 10 gilberts/cm. applied along the direction of a cube edge—the (100) direction—whereas it requires a field of about 420 gilberts/cm. to magnetise it to the same degree along a cube diagonal (111), and over 500 gilberts/cm. along a face diagonal (110).

Nickel crystals also possess similar marked directional magnetic properties in high fields, though in this material the cube diagonal is the direction of easy magnetisation. In the binary nickel-iron alloys, the directional properties are generally less strongly marked, depending on the composition, and in the alloy containing 66% nickel no directional properties at all can be detected.[16, 17]

Although these directional properties are of very great theoretical interest, it must be pointed out that they are only really pronounced at field strengths above about 5 gilberts/cm., when the material is more than half saturated. At lower field strengths, there appears to be little difference between the values of permeability of single crystals of iron measured in various crystal directions and, though precise measurements are difficult to carry out, the same is probably true of other ferromagnetic materials. However, some observers have considered that such materials as silicon steel and some of the complex nickel-iron alloys do show directional properties even under these conditions;[18] and it is thus of some interest to consider briefly how it is possible to take practical advantage of this characteristic.

In a normal sample of polycrystalline annealed nickel-iron alloy containing about 50×10^6 crystals to the cubic inch, each oriented at random, directional properties are naturally absent. It is obvious, though, that if all or a majority of these crystals could be arranged with their crystal axes parallel, the sample should show the directional magnetic characteristics of a single crystal. Such an effect can be produced by suitable cold-rolling or drawing operations, which are well known to have a tendency to orient the crystals in preferred positions relative to the direction of working. The first effect of cold rolling is merely to distort the crystal lattices, but after greater reductions, above about 35% in the nickel-iron alloys,[19] the crystals proceed to "line themselves up." Such preferred orientation, once produced, is not easily destroyed and is largely retained even after prolonged annealing at high temperatures. By careful rolling technique,[20] it has been found possible to utilise these principles commercially to produce silicon iron sheet in which most of the crystals are arranged [21] with a cubic axis within a few degrees of the direction of rolling. In strong fields (of about 4 gilberts/cm.), this material has a permeability of about 4,000 in the direction of rolling, whereas measured at right angles the permeability in only about one-tenth of this value.

For materials which are to be operated at low fields, it is doubtful, however, whether any very great improvements are to be expected from sheet with preferred crystal orientation. Slight improvements in the initial and maximum permeabilities of certain nickel-iron-chromium-copper alloys by the choice of optimum rolling conditions have been claimed,[18] but the general experience is that such improvements, if real, are very small.

This conclusion is, further, in good accord with modern theories concerning the nature of ferromagnetism. Detailed discussion of this point would be out of place here but, for a brilliant and extremely lucid account in English of the present status of ferromagnetic theory and of its relation to such phenomena as crystal anisotropy, reference should be made to a recent paper by Dr. R. M. Bozorth.[22]

For the present purposes, it must be sufficient to explain that the crystals of a ferromagnetic substance are conceived as being built up of small elements, each having the volume of a cube about 0.001 inch on an edge, and known as domains. The exact shape of a domain is unknown, and it is not certain whether the boundaries between these domains have any relation with the imperfections which have been postulated as existing in all metal crystals. At room temperatures these domains, in iron and nickel-iron alloys, are believed to be always magnetised to saturation in the direction of one of the six cubic axes of the crystals; and the magnetisation of the material as a whole is believed to depend on the extent to which all the domains are aligned. In an unmagnetised material, equal numbers of the domains in each crystal are arranged with their magnetic axis along each of the six possible cubic directions.

It is suggested that the first effect of applying a weak magnetic field is to enlarge those domains which are magnetised in the directions of the field, the domains magnetised in other directions growing shorter. The ease with which this boundary movement can take place depends on the extent to which the material is stressed either internally or by applied forces. Thus the extreme susceptibility of high-permeability alloys to external strain is explained. On the other hand, the ease of boundary movement is only very slightly dependent on the orientation of the magnetic axes of the domains, and thus of the crystal axes, with respect to these weak applied fields.

With rather stronger applied fields, the direction of magnetisation of some of the domains can be caused to change suddenly by 90 or 180 degrees so as to be more closely aligned with the external field. The net result of these changes on the magnetisation of the alloy as a whole will obviously depend largely on the relation between the direction of the applied field and the crystal axes—and in these stronger fields single crystals will obviously show directional properties.

Normally, according to this theory, the six directions along which a domain may be magnetised are related to the crystal axes of the alloy. It would seem, however, from some recent experiments that, if certain alloys are cooled slowly in a magnetic field from a temperature above the Curie point, it is possible to align the domains parallel to the applied field.[23, 24] It is suggested that when the domains cool below the Curie temperature and thus first develop their magnetism, stresses are set up. If, therefore, they are aligned in any given direction by an external field, and cooled very slowly, there will be an opportunity for stress relief to occur, during which the domains will actually change their shape. Subsequently, it will be very much easier to magnetise the material in the direction of the field which was applied during cooling than in any other direction. So far, the observations on which this theory has been built appear to have been confined to tests on polycrystalline material, but the results are very impressive. Of the alloys in the nickel-iron series, that containing 65% nickel has been found to be most susceptible to the influence of a magnetic field applied during cooling. With this composition the maximum permeability can be increased from 5,000 to 250,000 by cooling slowly from 700° C. in a field of 15 gilberts/cm. The reason why the alloy of this particular composition is most susceptible to heat treatment in a magnetic field has been explained on the grounds that the temperature of its Curie point is a maximum for all the alloys in the nickel-iron series. This means that the temperature at which the domains first become magnetised is a maximum and that there is thus a maximum opportunity for plastic flow. This explanation is supported by the observation that in the nickel-iron-cobalt series of alloys, high values of maximum permeability are, in general, obtainable only in the region where the Curie point is above 500° C. In the other alloys, the material is too cold and is insufficiently plastic to yield at the temperature at which the domains are first magnetised. On the other hand, it may be significant that the alloy of 65% nickel, 35% iron is remarkable as showing no directional magnetic properties, and that this characteristic also possibly influences its behaviour when heat treated in the manner under discussion.[17]

Reference has already been made to the effect of cold rolling in producing a preferred crystal orientation which persists even after annealing, and to the manufacture by this process of silicon-iron sheet having directional magnetic characteristics. Cold rolling operations also produce in some nickel-iron alloys certain magnetic characteristics which are not commonly encountered in sheet material. It has been found that unannealed cold rolled sheet shows very little hysteresis loss in feeble alternating magnetic fields and, in addition, has a permeability which, although low in value, remains unaltered as the field strength is increased up to quite large intensities. Furthermore, the permeability can be made to remain virtually unaffected after the material has been subjected for a short time to intense magnetic fields.

The development of such cold rolled sheet with a permeability between 50 and 100, which remains fairly constant up to field strengths of about 10 gilberts/cm., and with a stability below about 1%, has recently received considerable attention in Germany.[25, 26] This product has been called "Isoperm."

Nickel-iron alloys with from 40 to 60% of iron were first studied but it was found that, in cold rolling, reductions which yielded the minimum values of stability did not result in the lowest hysteresis loss. Additions of aluminium up to about 4% gave improved results but increased the hardness of the alloy and made rolling difficult. Alloys containing 36% or 40% of nickel with up to 15% of copper, however, proved more satisfactory, the precise characteristics obtained depending both on the degree of reduction by cold rolling and the heat treatment applied previously. Using a 50–50 nickel-iron alloy, it has also been found possible to increase the permeability by a low temperature heat treatment at 400° C. which leaves stability and hysteresis losses unchanged.[27]

Laüe X-ray photographs show that in the heavily rolled 50% nickel-iron strip annealed at 400° C., the crystals are oriented (with a dispersion of only 5–10%) with one of the cube sides on the rolling surface and one of the edges in the direction of rolling. Magnetic tests on this tape show, as might be expected, that it possesses directional properties. The special characteristics of low hysteresis loss in the cold rolled tape cannot, however, be explained on the grounds of favourable crystal orientation alone; and it has therefore been suggested [27] that the residual stresses play their part also by causing most of the domains to be magnetised in either of the two directions at right angles to the length of the tape. When such tape is made into a core, the applied alternating field tends to orient the domains so as to point alternatively along the two longitudinal directions, and it is suggested that minimum work will be expended if the domains are originally in the mean position at right angles to the run of the tape. This theory, incidentally, requires that the effect of the small magnetising fields produced in a loading coil should be to move the magnetic axes of the domains through a small angle; whereas the usual conception is that the directions of magnetisation change only through 90 or 180 degrees under such moderate stimuli. Thus, the effect of cold rolling on these alloys may be considerably more complex than this hypothesis suggests. One possibility is that the cold working causes precipitation of a disperse phase,[28] similar to that produced in other constant permeability alloys; but all explanations must in the present state of knowledge be extremely speculative.

Impurities

Thus far, this review has dealt with the characteristics of alloys made by high frequency melting from commercially pure materials such as electrolytic or Mond nickel, Swedish iron, and so forth. Small amounts of a number of impurities are inevitably present, and undoubtedly exert a harmful effect on the magnetic properties obtainable.

It has been explained that all high-permeability alloys are extremely sensitive to the effects of internal or applied stresses. It appears likely, also, that if elements are present in the alloys which tend to strain the crystal lattice, magnetic softness will be impaired. The elements carbon, oxygen, nitrogen, and sulphur are of this type, for instead of replacing atoms in the nickel-iron lattice, they crowd into interstitial positions.[29] These elements are, in fact, found to be most injurious to the permeability characteristics; and it seems most likely that their presence in varying small amounts is one of the main causes of the quite wide differences which are frequently found between the magnetic properties of successive melts of the same alloy. Varying amounts of dissolved gases such as carbon monoxide or methane, as well as the presence of slag inclusions, are also possible sources of non-uniformity.

On account of the experimental difficulties in making accurate determinations of small quantities of carbon, oxygen, and nitrogen, the extent of their influence on the nickel-iron alloys must remain largely a matter of inference. For iron, considerably more data are available,[30] and it is clear from the most recent work that both carbon and, particularly, oxygen exert an especially damaging effect on maximum permeabilities, even when present in minute quantities, well below 0.01%, but are not additive. The improvements which can be brought about by the removal of impurities from iron are very strikingly shown by the following figures:[31, 36]

Date	Authority	Material	Maximum Permeability	Hysteresis Loss
1885	Ewing	Wrought Iron	2,600	5,000
1900	Hadfield	Swedish Charcoal Iron	2,600	2,700
1913	Breslauer	Annealed electrolytic iron	11,500	1,440
1915	Yensen	Vacuum fused electrolytic iron—probably contained hydrogen	25,800	660
1928	Yensen	Vacuum fused electrolytic iron—probably contained hydrogen	61,000	300
1935	Adcock & Bristow	Vacuum fused iron, purest made at National Physical Laboratory. Total impurities, 0.0113%	14,360	—

It is interesting to speculate on the magnetic properties which might be expected from absolutely pure iron, if ever it is found possible to produce such material, and Yensen has recently ventured the prediction[30] that a single crystal of pure iron containing no oxygen and 0.001% carbon would have a maximum permeability of 500,000 and a hysteresis loss of 20 ergs per cc. per cycle. It will be noticed that these properties are rather superior to those of the best nickel-iron alloys known, and it is natural to enquire further whether the action of the nickel and other alloying elements may not be to neutralize in some way the deleterious effects which the interstitial impurities have on iron. One suggestion[32] is that the nickel-iron alloys, when fairly rapidly cooled, retain the impurities in solution and only precipitate them on slow cooling. It seems doubtful, however, whether the behaviour of the permalloys can be explained on so simple a basis.

Apart from the effect of the interstitial elements, greatest interest probably centres around the part played by hydrogen absorbed or combined in these alloys. The facts are that treatment of iron and—to a less extent—of some alloys in hydrogen very greatly improves their magnetic properties. By heating Armco iron in hydrogen (for 18 hours at 1480° C., followed by 18 hours at 880° C.), for instance, Cioffi[33, 7] has produced samples in which the initial permeability has been increased from about 250 to 20,000, and the maximum permeability from 7,000 to 340,000. Similarly, by heating 3.8–78.5–17.7 molybdenum-nickel-iron alloy to 1400° C. in hydrogen, the value of initial permeability has been increased from the normal value of about 20,000 to 34,000, and the maximum permeability from 75,000 to 140,000. The 50–50 nickel-iron alloy is particularly susceptible to improvement by this treatment, and for some years hydrogen-annealed sheet, made from alloy which has been melted under hydrogen, has been available commercially in America.[34, 35]

Views concerning the nature of the action exerted by hydrogen have fluctuated between two extremes in recent years. When this phenomenon was first recorded, it was considered that the hydrogen, by entering into solution or combination with the metal, itself exerted some influence on the magnetic behaviour. Later, there grew up a belief that the effect of hydrogen was entirely one of purification, and that its beneficial action was due to its power of removing oxygen, carbon, and sulphur from the metal. At the present time, while it is recognised that hydrogen can effect considerable purification by prolonged action at high temperatures, nevertheless it is not considered that its beneficial action can be explained as being wholly one of purification. Recent researches at the National Physical Laboratory in England as well as elsewhere on the production and study of very pure iron have strengthened the belief that hydrogen must be classed as an alloying element which, when present in small quantities, modifies the characteristics of iron and many of the high permeability alloys to a very considerable extent.

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The Cape Town–Johannesburg Carrier Telephone And Associated Voice Frequency Telegraph System

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General

IT is felt that this project merits a general description since it is comprehensive in its features and of proved reliability in service under difficult conditions.

The facilities at present afforded by the system are fifteen voice-frequency full-duplex telegraph circuits and two carrier telephone channels in addition to the usual audio telephone outlets. The telegraph channels can be increased to eighteen when the need arises.

The telephone circuits are brought out on the long distance boards at Cape Town and Johannesburg and used for South African and overseas traffic. Creed Page Teleprinters are used almost exclusively for the telegraph traffic although Creed Morse equipment is worked on one or two channels. In addition to the usual direct facilities between the telegraph offices of Johannesburg and Cape Town, two outlets are available for leased part-time private wire teleprinter service between Johannesburg and Cape Town Telex subscribers. Overseas telegraph traffic is also routed over the equipment.

It will be apparent from the foregoing that reliability of service is of prime importance since the system carries high grade traffic. From an equipment aspect, complete satisfaction has been attained. Line maintenance is difficult through sparsely populated country and a standby pair is available over the whole route. Faulty sections can thus be speedily replaced. Criticism of the policy of deriving so many and important facilities from one pair of wires has been expressed. This disadvantage must be admitted but the argument, to be complete, should consider the state of affairs presented when the whole pole line is in trouble following violent storms or accident. The breakdown party concentrates all its activities on restoring one pair (drop wire being used if necessary) and the system is routed over this circuit. The entire facilities of the system are thus available and the accumulation of traffic can be attacked without handicap. In South Africa, where alternative pole routes are not always available, this feature is worthy of merit and the Cape Town-Johannesburg system has several times proved its capabilities in this connection.

Installation of the equipment was commenced in April, 1934 and the circuits were opened to traffic on November 1st of that year. The equipment was made in the London factories of Standard Telephones and Cables, Limited, and installed by the Union Post Office in conjunction with an engineer of the manufacturers.

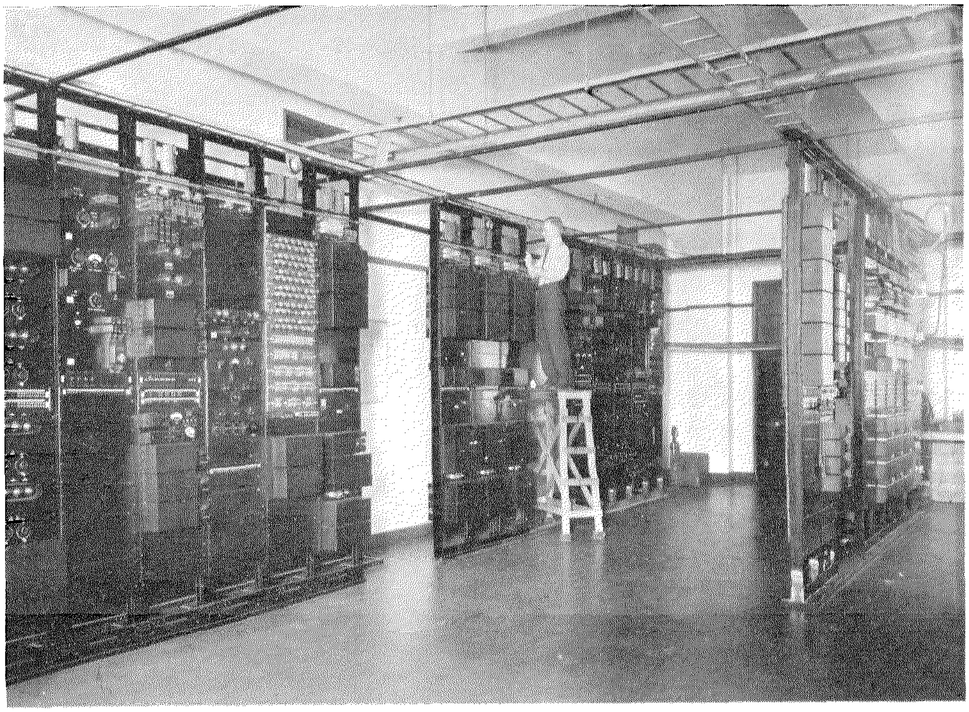
The System Layout

The Cape Town-Johannesburg route is 922 miles in length, running roughly north-east from Cape Town and passing through the mountainous scenery of Cape Province before reaching the high central plateau—Johannesburg being some 5,700 feet above sea level. The stormy seasons of the northern and southern halves of the route do not coincide and one end or the other is always liable to bad weather. The northern section, in particular, is exposed to very bad lightning and static conditions during the months between November and March.

The map (Fig. 1) indicates the location and spacing of the carrier repeater stations. Klerksdorp, Bloemhof, and Kimberley are of the "low gain" type (a maximum gain of 30 db. is afforded by the amplifiers) whilst the remaining three are "high gain" (a maximum amplifier gain of 45 db.).

With the exception of short carrier-loaded entrance cables at Cape Town and Johannesburg, the route is 150 lbs. per mile copper throughout. The configuration of the open wires changes several times due to the individualism of the early telegraph engineers of the once separate provinces which today comprise the Union of South Africa. For this reason also, the sections from Cape Town to Worcester and Fourteen Streams to Johannesburg are revolved, the remainder of the route having "point" transpositions on the telephone pairs. Preliminary line tests showed the existence of severe absorption peaks in the attenuation-frequency curves of the transposed sections, and extra transpositions were necessary in order to remove this trouble. It should be borne in mind that complete coordination of the circuits on the pole lead had not been obtained prior to the introduction of the carrier system. In fact, as indicated above, the route conditions existing were the result of miscellaneous additions spread over many years and, owing to diversified control, these additions were not coordinated in the most effective manner. In view of the consideration that the complete pole route is due for rebuilding shortly, the line work just prior to the introduction of the system was limited to that strictly necessary for its successful operation. A main line and a standby are available over the whole distance and are reasonably similar in electrical characteristics. In general, complete line sections are interchanged between the relevant repeaters in times of trouble.

The carrier loaded entrance cables at Johannesburg and Cape Town are similar—each approximately 1,000 yards in length, of 40 lb. multiple twin conductors and loaded with intermediate 3.5 mH coils at 250 yard intervals. With terminal compensating units the effective transmission of frequencies up to 43 kc./sec. is possible, and this range has been chosen in order to accommodate proposed broadcast channel systems. At present only two pairs are loaded.



Part of Johannesburg Toll Line Equipment

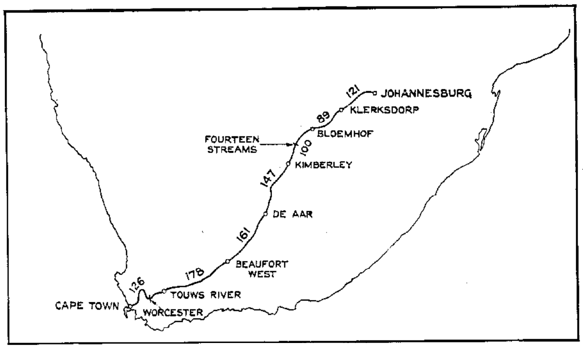


Fig. 1—Location and Spacing of Carrier Repeater Stations

The 3-Channel Carrier Telephone Equipment

The 3-channel carrier telephone equipment[1] is of the single side-band suppressed carrier type using the C.S. 3 frequency allocation (Fig. 2). Special carrier line filters enable an upper limit of 5,000 p : s to be obtained from the physical circuit in order to render it more suitable for the transmission of broadcast programmes. In its broad outline the carrier telephone system is similar to the systems described in previous articles. Two additions are, however, novel.

The lines upon which the system operate have a total overall loss during fine weather of approximately 150 db. at 30 kc./sec. The telephone channels are operated with a net loss of 6 db. between the long distance positions at the two terminals. The need for a precise and rapid control to offset the constantly varying line losses is very evident. Manual operation of repeater amplification would be cumbersome and would lead to loss of traffic time whilst the system levels were being adjusted.

Automatic gain control associated with the automatic pilot channel equipment was therefore introduced. Its main function is to change the repeater amplification in order to compensate for slow changes in line loss due to weather conditions. A steady pilot current is sent out by each terminal—these currents having selected frequencies within the relevant carrier ranges. At each repeater a loosely-coupled tuned circuit, bridged across the amplifier output, accepts only currents of the pilot frequency and the resulting voltage is fed to the grid of a rectifier valve. The anode current of the latter will thus vary with the line loss preceding the amplifier, and a meter in the anode circuit can be directly calibrated in decibels "up" or "down" with reference to a normal value. The anode current controls a marginal relay having limits of plus or minus 0.5 db. and operation of this starts a sequence of events leading to the stepping of a rotary switch. The bank contacts of the switch are connected to an attenuator inserted ahead of the amplifier and, as the switch rotates, attenuation is removed or inserted until the appropriate correction is obtained.

In the repeater stations the above equipment is in duplicate—one set maintaining the levels in the Johannesburg-Cape Town and the other in the opposite direction. In order to ensure that the necessary correction is always made by the requisite amplifier, a time delay is introduced between the operation of the marginal relay and the stepping of the switch. This delay increases progressively from repeater to repeater (see Fig. 3).

The pilot equipment also gives visible and audible alarms if the level drops more than 6 db. below its normal value. The complete equipment for a repeater station can be mounted on a 8′6″ bay.

In practice, the pilot channel has proved successful—fully justifying its installation. The stepping of the rotary switches passes unnoticed by the telephone subscribers and merely causes a small transient increase in the distortion on the telegraph channels.

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[1] For all numbered references see list at end of paper.

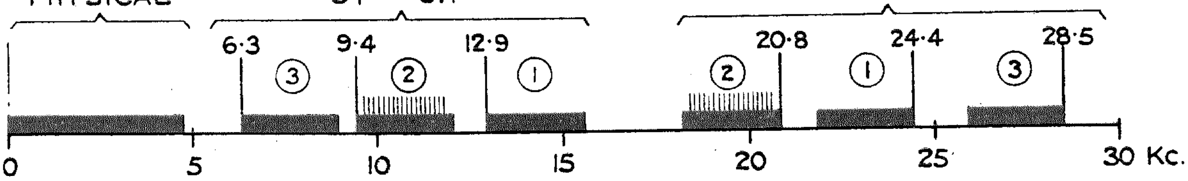
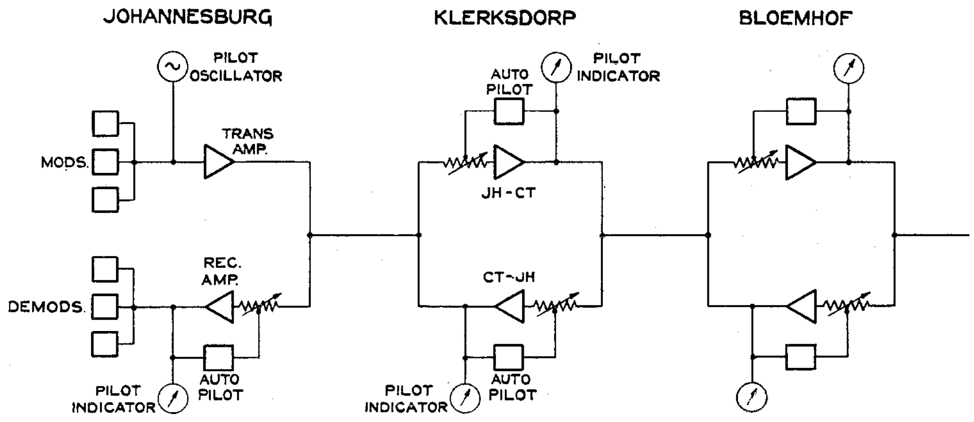


Fig. 2—Frequency Allocations



PILOT DELAY SECONDS		REPEATER STATION
CT-JH DIRECTION	JH-CT DIRECTION	
52·2	–	JOHANNESBURG
37·6	5·5	KLERKSDORP
26·8	8·6	BLOEMHOF
18·9	12·9	KIMBERLEY
12·9	18·9	DE AAR
8·6	26·8	BEAUFORT WEST
5·5	37·6	TOUWS RIVER
–	52·2	CAPE TOWN

Fig. 3—Schematic of Automatic Gain Control

As shown in Fig. 4, the output from the V. F. Telegraph system is fed into the modulator of channel 2. The terminal and repeater amplifiers, therefore, handle the products of telephone modulation from channels 1 and 3, and the telegraph modulation from channel 2. Speech transients of high level could thus produce cross modulation in these amplifiers, leading to interference with the telegraph signals. As a preventive measure, voltage limiters are inserted between the hybrid coils and modulators of the two telephone channels. A simple, but very effective, device is used for the purpose, consisting of a selected neon lamp across the secondary of a step-up transformer. The primary is shunted across the modulator input. Undue voltage across the primary winding causes the lamp to "blink." The impedance across the modulator input is then quite low, and the transient voltage effectively reduced to a safe value.

The V.F. Telegraph Equipment and Its Application to the Telephone System

The telegraph equipment has previously been described in detail.[2] The equipment in use is so similar that a further description is not warranted.

The present facilities of fifteen full duplex channels are capable of easy extension to eighteen, when required. All circuits, with the exception of an engineering order wire, are extended to the telegraph offices at Cape Town and Johannesburg. Operating practices are standard.

The transmitting side of the telegraph system feeds into the modulator and the demodulator output is connected directly into the receiving telegraph equipment. In effect four-wire working is obtained.

The maximum power level on the line due to a telegraph channel marking is approximately 3.5 milliwatts. This results partly from the transmitting gain of the carrier telephone system,

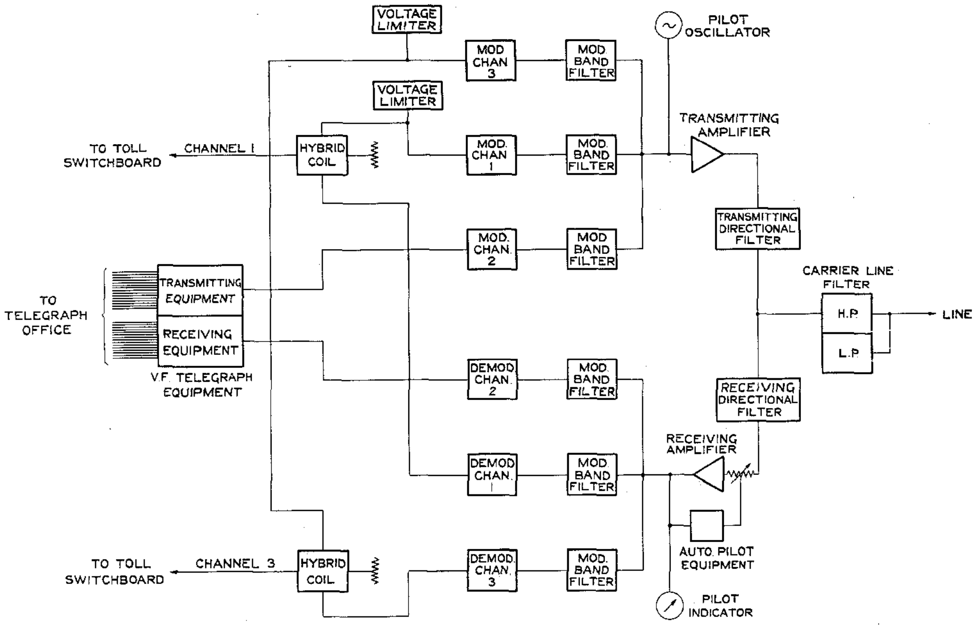


Fig. 4—Schematic of Carrier Terminal Equipment

i.e., 20 db. from modulator input to the line itself. The average power for a physical telegraph circuit working on an open wire line may be of the order of 3.5 watts (120 volts 30 milliamps).

The circuit between modulator input at the transmitting terminal and the demodulator output at the receiving terminal is operated at a gain of 8 db. This is in rough agreement with V.F. telegraph systems operated on a four-wire cable circuit and has been adopted on the Cape Town-Johannesburg system for general convenience.

Performance of the System

The operation of a carrier telephone system over 1,000 miles of open wire line has been effected elsewhere and no difficulties were experienced in securing high grade speech circuits in this instance. The automatic pilot channel is of material assistance in maintaining a 24 hour service substantially free from trouble. Care has to be taken to maintain line levels and a test line-up is carried out each week in order to check pilot channel operation.

Minor line faults, in general, leave the carrier telephone channels unaffected although the physicals may be unworkable. In times of severe static and thunderstorms slight noise becomes apparent on the channel using the lowest frequency band (channel 3 from Cape Town to Johannesburg) but the circuit is fully commercial. Broadcast programmes are frequently routed via a telephone channel between the two terminals. The frequency range is naturally limited but the absence of noise is appreciated.

Before describing the performance of the V.F. telegraph circuits, a short résumé of atmospheric conditions will be of interest. The route from De Aar to Johannesburg is liable to severe atmospheric electrical conditions from November to March—the intensity of these storms from a lightning point of view probably ranking with any experienced elsewhere.

High winds, driving dust against the lines, cause electrostatic voltages of the order of 300. The humidity in general is very low and high insulation conditions prevail. Rainfall is scanty. Two associated problems arise—protecting the equipment from injury and minimising the interference with the telegraph circuits.

It is believed that the first difficulty has been overcome by carbon-block lightning arrestors situated on the first and fifth poles outside an office. The gaps of these protectors are graduated, as shown in Fig. 5. Choke coils, consisting of 16 turns with an average diameter of 3″, are constructed of 7/22 V.I.R. cable and inserted in the lines between the office and the terminal outside protector.

Earth connections to all protectors are tested frequently. Difficulty is experienced in securing low earth resistances in some districts but, in general, values less than 3 ohms can be obtained. Inside the offices the usual line fuses and mica gap protectors are used.

The second problem is more difficult. The mutilations shown by the teleprinters originally covered, on the average, three or four letters. This time interval depends on the performance of the protectors and equipment under violent transient conditions. In this connection the vital points are, perhaps, grid-blocking of the amplifiers and the characteristics of the V.F. detector panels.[2] Grid-blocking of amplifiers has been reduced by the introduction on the line of a device shown in Fig. 5. The close coupling M between the two inductances L_1 and L_2 ensures that both protectors operate almost simultaneously. A discharge surge from a highly charged wire via the equipment and to earth through the operating protector is thereby avoided. Precise information is difficult to obtain but it is believed that the mutilations on the teleprinters have been reduced to a one letter interval by fitting these devices at all relevant points. The characteristics of the V.F. detector panels are such that the effect of a transient is greatly minimised and, in many cases, the receiving relays are not operated.

To prevent the accumulation of static charges on the lines, special repeating coils have been inserted on each side of each repeater station. The centre point of the line side of these coils is earthed. The complete protection is thus as illustrated in Fig. 5.

Mutilations have now been reduced to a low figure except in cases of severe storms near the route. Further investigation is being carried out. An automatic device in Johannesburg records all "flicks" and the information thus obtained is used to determine the efficacy of modifications.

With the above exception the telegraph circuits are capable of reliable, consistent service.

The measured distortion of the telegraph signals is of the same order as that obtaining on V.F. Telegraph systems operating over loaded cable circuits. Routine measurements of distortion are carried out by means of telegraph distortion measuring sets.[3]

The authors' thanks are due to the Chief Engineer of the Posts & Telegraphs Department of the Union of South Africa for permission to publish the information and photographs contained herein.

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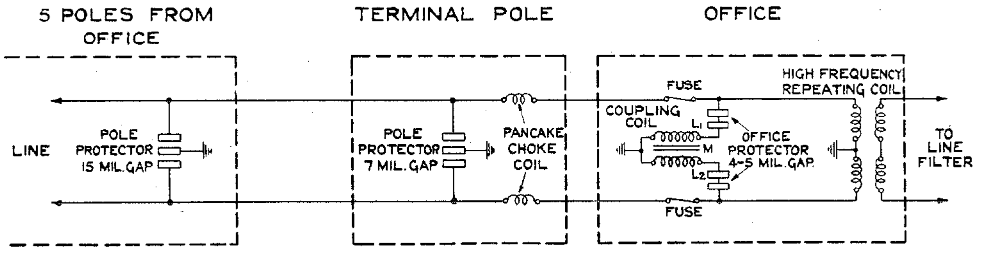
5 POLES FROM OFFICE
TERMINAL POLE
OFFICE
LINE
POLE PROTECTOR 15 MIL. GAP
POLE PROTECTOR 7 MIL. GAP
PANCAKE CHOKE COIL
FUSE
COUPLING COIL
L_1
M
L_2
OFFICE PROTECTOR 4-5 MIL. GAP
HIGH FREQUENCY REPEATING COIL
FUSE
TO LINE FILTER

Fig. 5—Schematic of Line Protection

Telephonic Communications in China

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DURING the past years, a serious effort has been made by those in authority in China for the establishment within the country of a good telephone communication system, both by the installation of new plant and by making improvements to the existing lines and equipment. This work has been carried out despite handicaps, including shortage of funds available for this type of work—it being considered more important to expend the money available on railroads and highways. Additional factors involved have been political disturbances, which in a number of cases have necessitated complete changes of plans; and the difficulties introduced by the existence in certain districts of bandits who have frequently completely removed the telephone wires. This latter difficulty is, however, not as serious as formerly, since the building of highways, in many cases, has provided the authorities with means for quickly reaching places where the presence of bandits is indicated. A country as vast as China is not easy to control, and it is only by close cooperation between the Ministry of Communications and the various operating Administrations that long distance telephony is becoming practicable.

Nearly every large city in China and also a great number of the smaller towns have telephone exchanges of one type or another, but facilities enabling subscribers in one town to talk to those in another have until recently been practically non-existent. Improvements and new projects recently undertaken have aimed at overcoming this deficiency.

There are approximately 164,000 telephone subscribers in the whole of China, of which approximately one-third are in the Shanghai area, which includes seven exchanges with over 52,000 subscribers in the system operated by the Shanghai Telephone Company, an associate company of the International Telephone and Telegraph Corporation. This company's system has been described in *Electrical Communication*.[1]

The Greater Shanghai area contains ten automatic exchanges with approximately 52,000 lines of automatic equipment. Automatic exchanges have also been installed in the cities indicated in the accompanying table.

AUTOMATIC EQUIPMENT INSTALLED IN CHINA

	No. of Lines
Canton	10,000
Changshu	1,000
Foochow	1,500
Hangchow	3,000
Hankow	8,500
Nanking	6,000
Shanghai Area	52,000
Swatow	1,000
Tientsin	9,000
Tsingtao	4,000

Automatic equipment installed in China totals 96,000 lines—65% Rotary and 35% Step-by-Step.

It is interesting to note that Peiping, with 16,400 subscribers, is still operating on the common battery manual system. Tientsin, in addition to three automatic offices with 9,000 lines, has two common battery manual offices with 6,000 lines. Other common battery manual exchanges of any size are: Soochow (2,000 lines), Tsinan (3,000 lines), Amoy (2,200 lines), and Wusih (1,400 lines). Ningpo has 2,100 magneto lines. Doubtless, when more important projects are completed, these common battery manual exchanges will gradually be converted to automatic.

With the exception of a cable installed underground between Canton and Hongkong, all toll lines are carried overhead. In the past, iron wire was mostly used, but recently an endeavor has been made to substitute copper wire on routes which are important from a traffic point of view. For some years, a few toll circuits have existed between Shanghai and Nanking, but up to two or three years ago the chance of getting a good connection over these circuits was very remote, chiefly on account of noise and poor transmission. However, about two years ago, a new pole route with copper wires was constructed following the new highway and this constituted a great improvement. Other long distance circuits which at present exist are those between Tientsin and Peiping, and Shanghai and Hangchow (Chekiang Province), as well as a comprehensive toll network in the latter Province. At present Hankow, with a population of approximately 1,500,000, is unable to communicate by telephone with any of the other larger cities in China.

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[1] "The Reconstruction of the Shanghai Telephone System," by J. Haynes Wilson, *Electrical Communication*, July, 1932.

In Canton, there is an exchange of the Rotary type having a capacity of 10,000 lines; and the cable between Canton and Hongkong provides efficient and stable toll circuits, but no means exist at present for communication between this system in the South and the cities in Central and Northern China.

The Hongkong-Canton cable was manufactured and installed in 1931 by Standard Telephones and Cables, London, and has been fully described in *Electrical Communication*.[2]

It is apparent from the above that the present state of telephone communications in China is poor, but the work now being undertaken by the authorities is such that this situation will, within the course of the next year or so, be considerably changed. The Government has been able to make arrangements with the British Boxer Indemnity Fund for the supply of a considerable amount of up-to-date equipment for making improvements in its long distance telephone system. The money which has been obtained from this source has been devoted to the establishment of two main systems, both of which will be described in the future in *Electrical Communication*. The first, which was nearing completion while the present article was being written, comprises several high power, short wave radio equipments which will provide telephonic communications between Shanghai, Hankow, and Canton. The second comprises equipment and line plant which will provide a long distance communications system by wire between important points in a number of provinces.

The planning of this system was carried out by the Chinese Telephone Administration in cooperation with Standard Telephones and Cables, London, which is supplying the toll boards, repeater equipment, and the cables for river crossings. The lines themselves have been designed in accordance with the most modern practices so that, at a future date, additional circuits can be obtained by the installation of carrier telephone equipment. Where the route crosses the large rivers of China, cables of special design and suitable for carrier telephony operation have been installed. The repeater equipment, located at a number of points along the route, is of the latest design and manufacture, and is of the type described in an article entitled: "The New Standard Repeater Equipment,"[3] by J. S. Lyall. Facilities provided on the toll boards which are being installed, will enable the speedy establishment of connections in the most efficient manner. It is expected that communication over the new system will be established between Shanghai and Hankow before the end of the present year.

An interesting means of providing telephone communication is being adopted in South China in the district around Canton, where the country is so cut up by rivers and creeks that the erection of pole line routes would be a difficult proposition. The authorities have decided in this case to employ 7–10 meter ultra-short wave radio facilities whereby a number of towns, which thus far have been isolated telephonically, will be brought in contact with the Canton telephone system.

The Ministry of Communications, in planning its telephone communication system, has not overlooked connections to other countries and has already established, by means of short wave radio, a circuit between Shanghai and Japan. For the past year or more, it has been carrying on tests with both England and America and it will not be long before China will be connected by radio to the large international telephone networks of the world.

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[2] "Hongkong-Canton Toll Telephone Cable," by P. T. Carey and R. E. Burnett, *Electrical Communication*, April, 1932.

[3] "The New Standard Repeater Equipment," by J. S. Lyall, *Electrical Communication*, April, 1935.

Universal Telephone Set

THE wide variety of telephone sets which it has been necessary to manufacture and stock has presented a difficult problem to telephone manufacturers and operating telephone companies. Three different methods of operation, namely, local battery, common battery manual, and automatic, together with the need for sets for both table and wall mounting, are the causes for so many varieties.

The Bell Telephone Manufacturing Company,

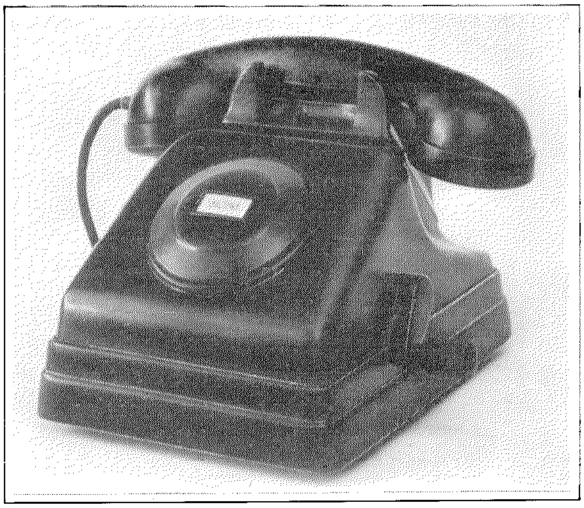

Fig. 1—Universal Telephone Set Arranged for Local Battery Table Mounting.

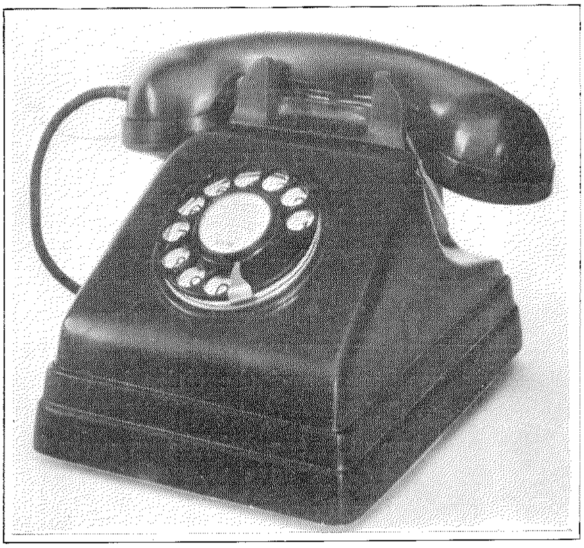

Fig. 3—Universal Telephone Set Arranged for Automatic Table Mounting.

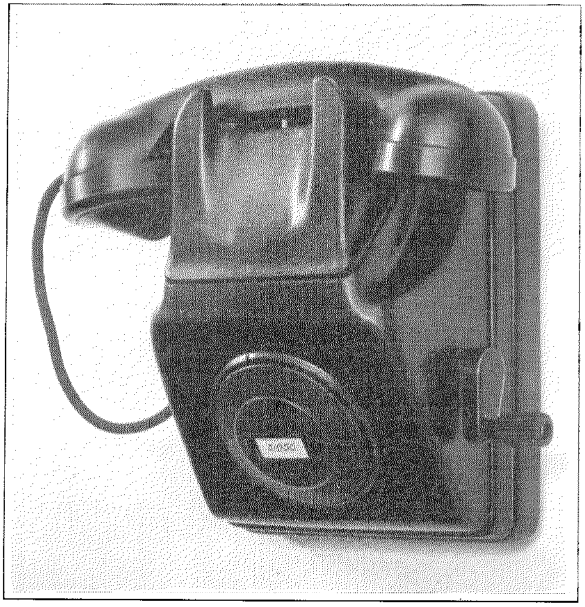

Fig. 2—Universal Telephone Set Arranged for Local Battery Wall Mounting.

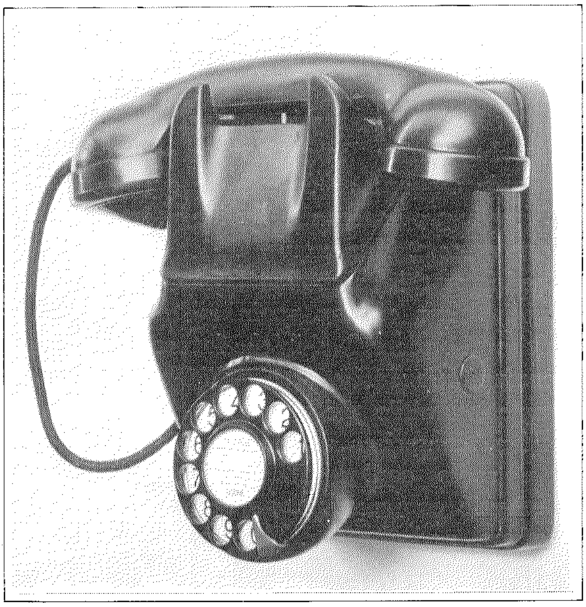

Fig. 4—Universal Telephone Set Arranged for Automatic Wall Mounting.

Antwerp, Belgium, has taken a notable step towards the alleviation of this condition by the production of a new convertible bakelite set. The four illustrations show the appearance of what is fundamentally the same set:

Fig. 1 shows the set arranged for local battery table mounting;
Fig. 2, for local battery wall mounting;
Fig. 3, for automatic table mounting;
Fig. 4, for automatic wall mounting.

Common battery manual sets arranged for table and wall mounting would look the same as Figs. 1 and 2, respectively, except that the generator crank would be omitted and the crank hole covered.

It will be evident that a table set may be converted into a wall set, or vice versa, by simply rotating the microphone cradle 180°. This flexibility is achieved by inclining the plane of the cradle mounting surface at an angle of 45° with the plane of the set mounting surface.

In case the set is required for automatic operation, a dial adapter is placed under the dial when wall mounted and omitted when table mounted (Figs. 3 and 4). Thus the correct dial angle can be readily obtained regardless of the position in which the set will be mounted.

Magneto sets may be converted to manual common battery sets by changing the induction coil and omitting the generator crank. The addition of a dial and dial adapter, when necessary, converts the common battery manual into an automatic set.

The great flexibility of the new set will be appreciated from the preceding brief description, and it will be apparent that this set comes very close to being universal in its application.

The New Steel Tone Tape Machine*

AS A result of recent successful trials of the Steel Tone Tape machine by the Reichsrundfunk-Gesellschaft, problems involving electromagnetic tone recording are being given increased attention. As compared with film and disk methods, electromagnetic recording was neglected for a considerable period. The viewpoint was that its application would be limited to telephone signaling and control circuits and to the dictation of letters, messages, etc. Electromagnetic recording, however, as compared with the other two methods, has definite inherent advantages: before recording is completed, its quality can be tested; frequent reproduction does not cause deterioration; and, furthermore, erasure is a simple process and the tape can be reused indefinitely. In addition, electromagnetic recording and reproduction are not affected by external vibration, and relatively long uninterrupted use of records is practical. These characteristics are especially useful in the broadcasting field where it may frequently be desirable to record lengthy reports or speeches, and where facilities are required for making records while on a moving vehicle, such as a train or motor car. That the Steel Tone Tape machine is peculiarly fitted to meet these requirements has been shown by the experience of the Reichsrundfunk-Gesellschaft.

In the present article, the general technical considerations involved in the development and construction of the Steel Tone Tape machine will be discussed.

Mechanical Construction of the Steel Tone Tape Machine

Fig. 1 shows a view of the commercial machine which for purposes of transportation was designed in trunk form. Two large drums, "*a*" and "*b*," carry the steel recording tape which is 3 mm. wide and .08 mm. thick. Between these drums the steel tape travels through the erasing and recording mechanism "*c*," and the two reproducing mechanisms "*d*," as well as over the four guide rollers "*e*," and the main driving wheel "*f*." The arrangement is depicted schematically in Fig. 2.

Briefly, the mechanical considerations involved in the development of the Steel Tone Tape machine were the following:

(1) The steel tape, during recording and reproduction, must always travel at the same speed at a given stage of its progress through the electromagnetic mechanisms or "heads." For practical reasons, therefore, a constant tape velocity is desirable. Velocity restrictions obviously are imposed by the necessity of adhering to a definite frequency band.

(2) Both drums "*a*" and "*b*" must be arranged for winding up the steel tape. After each recording, the tape must be returned to the initial recording position.

(3) To achieve flexibility, the drums "*a*" and "*b*" must be readily interchangeable. After a tape has been used for recording purposes, it must be possible to readily substitute an unused tape for a subsequent recording.

It might be thought desirable to arrange either drum "*a*" or "*b*" for driving purposes according to need. This would be impracticable, however, due to the requirement that the tape be arranged to travel at a constant velocity; for, during winding and unwinding, the effective cross-sections of the drums with the tape partially wound thereon, change continuously. The tape is, therefore, driven by the drum "*f*" (Figs. 1 and 2). This drum, by means of a reducing gear, is mechanically connected to a motor and maintains a practically uniform speed, so that the tape is transported at constant velocity. In order to prevent slippage, a seamless textile belt, which is kept under tension, travels over "*f*," "*e*," "*l*," and "*e*," as indicated in Fig. 2 and maintains the steel tape tightly pressed against the main driving drum "*f*."

To meet requirement (2) above, the following construction was adopted:

(1) A driven drum on which the unrecorded tape is placed;

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* Translated and republished in slightly abbreviated form from "Die neue Stahlton-Bandmaschine," ***Lorenz Berichte*** (No. 1, January, 1936), Technische Nachrichten der C. Lorenz Aktiengesellschaft, Berlin-Tempelhof.

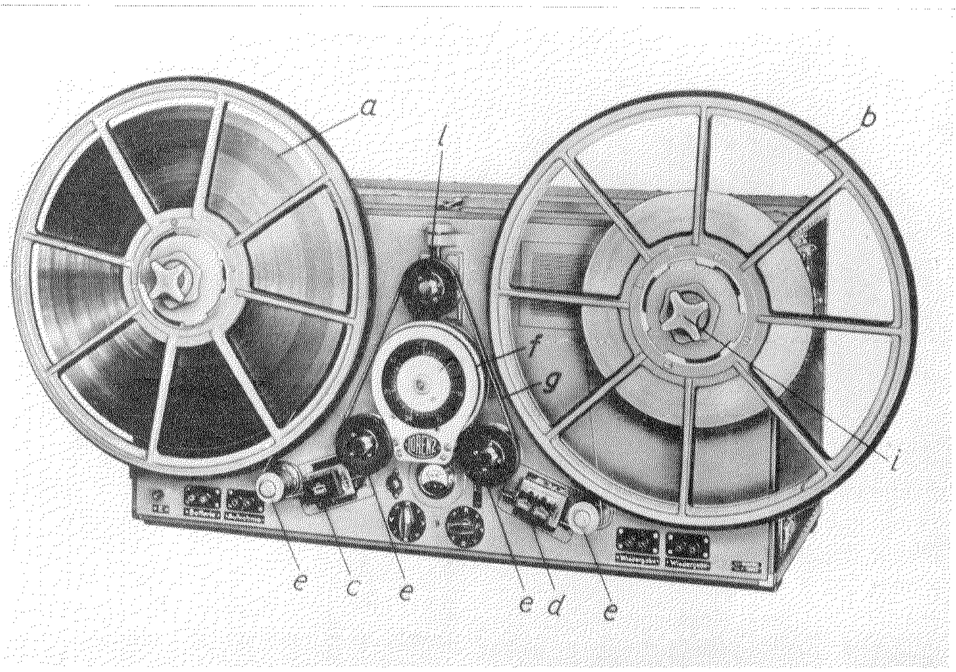

Fig. 1—Lorenz Steel Tone Tape Machine.

(2) A main driving drum "*f*"; and

(3) A driving drum on which the recorded tape is wound.

The design of the machine is such that the velocity of the tape on the three drums is identical. The driving tape drum must tend to accelerate in order to exert tension on the tape. It is, therefore, frictionally coupled to a driving mechanism which rotates at a velocity somewhat higher than is required for winding up the tape. The tendency of the driving drum to step ahead is counteracted by slippage at the frictional coupling. In the case of the driven drum, it is sufficient to provide braking to prevent undue acceleration.

Fig. 3 illustrates schematically the design of the driving drum. To wind up the steel tape "*a*" the drum "*b*" must rotate in the direction indicated by the arrow. The drum is driven by means of the belt "*d*" and the pulley "*c*" through the agency of the reversible coupling "*e*" and the frictional coupling "*f*." To convert the driving drum into the driven drum, when it is necessary to unwind the tape, "*e*" is held against the body of the machine "*h*." The axle "*g*" is thus held in a fixed position and the coupling "*f*" then operates as a brake on the drum.

To meet the third or interchangeability requirement, each tape drum has a large center hole which fits on to a cylinder on the axle "*k*" in a manner such that any drum can be assembled on either machine axle as required. The manipulation involved in interchanging drums is simple and can be accomplished in a single minute by means of a simple tool.

The problems involved in starting and stopping the machine merit attention. Under these conditions, a relatively great mass must be respectively accelerated and decelerated rather rapidly for satisfactory operation. The possibility, for example, of failure of the motor current supply must be considered. In this event, difficulty would hardly be experienced with the driving tape drum, inasmuch as it is connected by a belt with the main driving drum. The driven drum, however, must be braked in the event of failure of the power supply in order to prevent continued revolutions which might cause the steel tape to become entangled with subsequent breakage on restarting the machine.

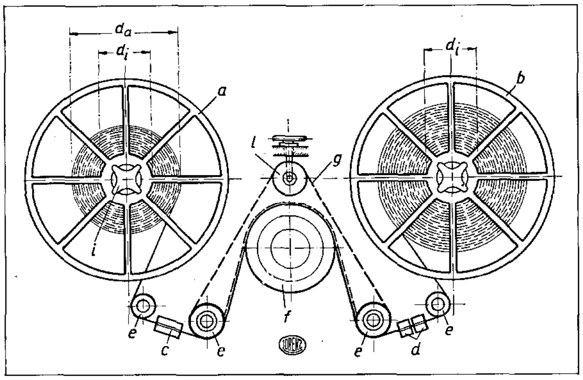

Fig. 2—Schematic Illustrating the Travel of the Steel Tone Tape.

The problem is simplified when stoppage occurs after a considerable period of operation, inasmuch as most of the tape is then unwound from the driven drum and its effective mass is smaller. In Fig. 4, the total drum weight is designated as *G;* the drum cross-section, d_a (the drum without the steel tape has a maximum diameter of $d_i = 20$ cm.); and the drum moment of inertia, *J*. Fig. 5 shows the relation of the length of operation versus the braking time for different braking moments. The weight of the drum without tape is taken as 4.6 kg. and its moment of inertia as 1.6 kg. cm.sec.^{2}, these figures being average for running periods between 20 and 40 minutes. In plotting the curves, the tape speed necessary for the required frequency band has been assumed to be 1.5 m./sec. The aim has been to provide the longest practicable recording period. From these curves, the relation of the elapsed recording to braking time will be evident. For the Steel Tone Tape machine, a compromise operating period of one-half hour has been chosen.

Constant braking on the driven drum and slippage of the driving tape drum obviously influence the size of the motor required. The power loss due to braking and slippage is:

$$N_v = \frac{736}{75} M_b(\omega_g + \omega_k - \omega_z) \text{ watts.} \qquad (1)$$

M_b is the braking moment which, because of the design, is alike for both the driving and the driven side, and is constant for a given total operating period; ω_k is the angular velocity of the constantly revolving half of the frictional coupling on the driving side; ω_z is the changing angular velocity of the driving drum; and ω_g is the changing angular velocity of the driven drum. ω_k is so chosen that it is always greater than ω_z. From equation (1), if $\frac{75}{736 M_b} = \alpha$:

$$\alpha \cdot N_v = \omega_g + \omega_k - \omega_z. \qquad (1a)$$

The relation between ω_g and ω_z, as will readily be apparent, is:

$$\omega_z = \frac{2\omega_g \cdot v}{\sqrt{\omega_g^2 k - 4v^2}}; \qquad (2)$$

and, therefore,

$$\alpha \cdot N_v = \omega_g + \omega_k - \frac{2\omega_g \cdot v}{\sqrt{\omega_g^2 k - 4v^2}}. \qquad (3)$$

v is the velocity of the steel tape, and k is a constant depending upon the operating period, and d_a^2 max.$+d_i^2$. $\alpha N_v = \omega_g + \omega_k - \omega_z$ has been plotted in Fig. 6 as a function of the elapsed recording time for a total recording period of 30 minutes. It follows that the power loss towards the end of the recording period is a maximum. The driving motor must, of course, be of sufficient capacity to take care of this maximum loss. Since, however, independent of the total recording period but towards its end, ω_g remains constant for a given cross-section d_i and a tape velocity of 1.5 m/sec., the maximum power loss changes only with ω_z. From the curve it will be seen, however, that the influence of ω_z

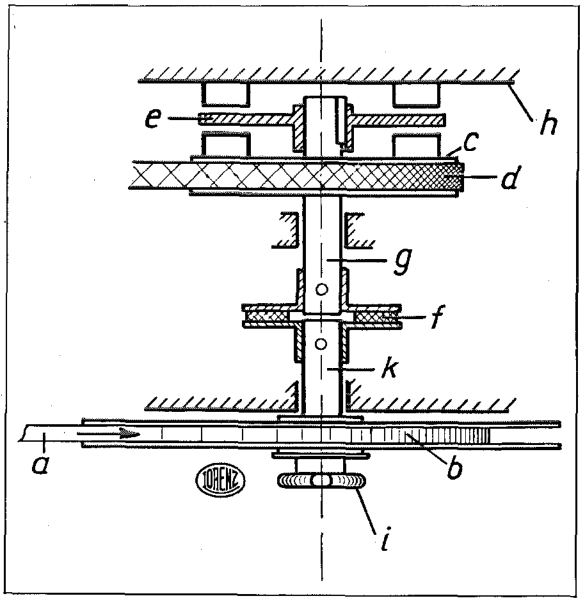

Fig. 3—Schematic of Drive of a Tape Drum.

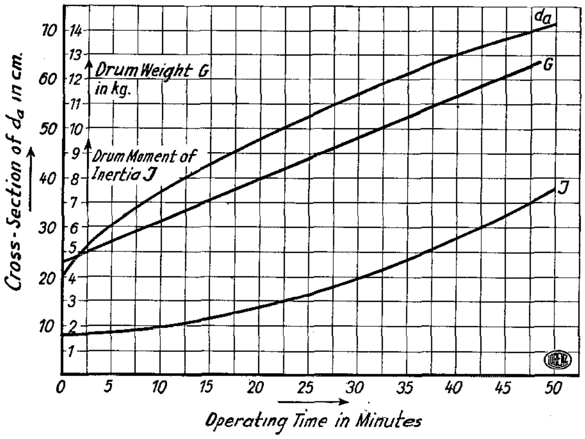

Fig. 4

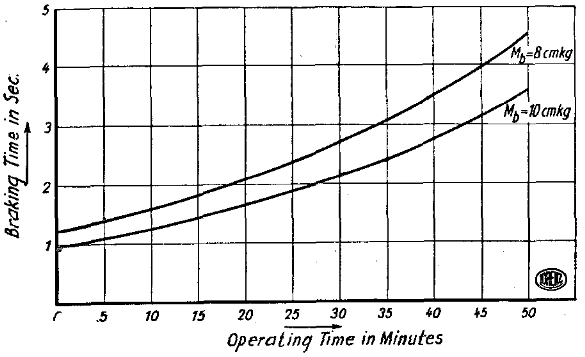

Fig. 5—Operating Time Versus Braking Time for Different Braking Moments.

with increasing time, approximately after 20 minutes, is no longer great. In fact, if the braking moment for any total running period could be held constant, the power loss would not be appreciably greater if a 45 minute instead of a 30 minute reproduction period were chosen. Since, however, with a specified braking time, the braking moment must increase with elapsed recording time (Fig. 5), α is no longer constant. The power loss, in accordance with equation (1), increases proportionally with the braking moment.

Magnetic Recording

Magnetic tone recording and reproduction, in recent years, have been the subject of a series of investigations and descriptive articles in the technical press.[1] In the development of the new tape machine for use in connection with broadcasting, experience up to date was utilized fully in order to achieve the requisite quality. Since a detailed description of the magnetic relations would be beyond the scope of this paper, only the fundamentals involved will be briefly considered. Three different operations are involved: (1) Erasure, (2) Recording, and (3) Reproduction. These three operations are performed with mechanisms which are alike in principle, viz., an erasure head, a recording head, and a reproduction head. These heads (Fig. 7) consist of cores "*a*" with spools "*b*." The cores "*a*" are movable longitudinally and are in each case offset slightly with respect to each other, and are pressed by means of springs "*c*" against the side of the tone tape "*d*." Fig. 7 illustrates the principle of the arrangement. The erasure and recording heads are arranged in a common housing and are shown in Fig. 8*a*; the reproduction heads, in Fig. 8*b*. The magnetic field in the cores and in the steel tape is illustrated by Fig. 9. The main lines of magnetic flow are indicated by *H*, and the stray flux by *St*. It will be noted that in the steel tape the flux *St* opposes *H*, and thus

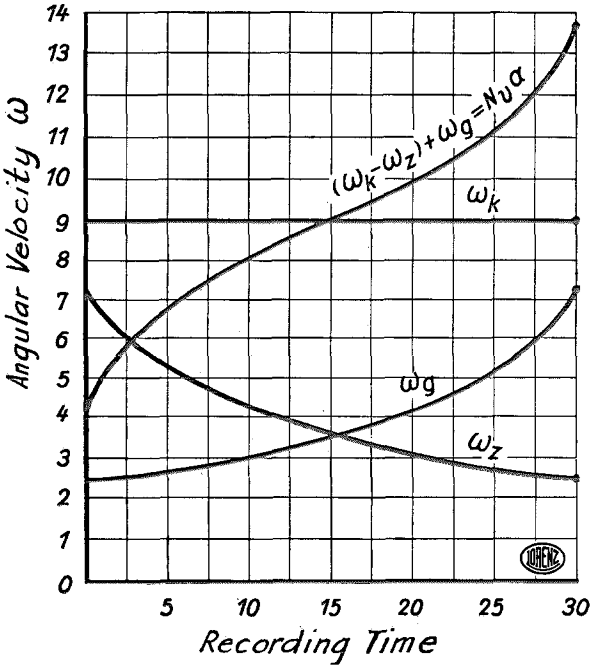

Fig. 6

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[1] Hormann: "Zur Theorie der elektromagnetischen Tonaufzeichnung" *E. N. T.*, 1932, Heft 10; E. Meyer und E. Schüller: "Magnetische Schallaufzeichnungen auf Stahlbänder," *Zeitschr. f. tech. Physik*, 1932, Heft 12; S. Begun: "Beitrag zur Theorie der elektromagnetischen Tonaufzeichnung auf Stahldraht," Dissertation Sonderdruck Studentenhaus, 1933; Dr. Hans Joachim von Braunmühl: "Magnetische Schallaufzeichnung im Rundfunkbetrieb," Funk, 1934, Heft 40.

the latter is somewhat diminished. To simplify the following description, the stray flux will be neglected.

Erasure of the record from the steel tape is accomplished by magnetically saturating the tape (point S on the magnetization curve of Fig. 10) by means of the erasure head. After the tape passes beyond its field of influence, magnetization falls to the point R. The coils of the recording head are energized with a constant current I_g in a direction such that the resulting flux is opposed to that of the erasure flux and, in the vicinity of the recording heads, the magnetization of the tape reaches the point V. After passing beyond this head, the tape magnetization is represented by V'. During the process of recording, an alternating current I_w is imposed on the direct current I_g. As a result of the current I_g+I_w, the magnetization of the steel tape in passing the recording head oscillates between V_a and V_b with the point V as a mean. Beyond the sphere of influence of the recording head, the corresponding values rise to V_a' and V_b'. Since counter magnetization only very slightly distorts the magnetization curve, it may be neglected. Maximum results depend on the selection of the point V and on the slope of the useful portion of the magnetization curve.

The foregoing discussion of the recording process applies only when the zone affected by the recording head is regarded as a point or at least as very small compared with the wavelength of the recording current. In the contrary case, the phenomena are extremely complex and their consideration would extend beyond the scope of this paper.

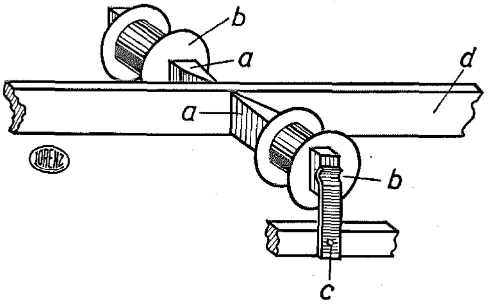

Fig. 7—Heads with Steel Tape, Illustrating Principle of Design.

The lateral distance "*a*" between the off-set cores, also the effective core width "*b*" (Fig. 9), are of controlling importance in connection with the zone of influence of the recording head. In order that these dimensions may be kept small, the cores are pointed and the off-set between the two cores is made as small as practicable. Fig. 8 shows the micrometer screw for adjusting this off-set, which must have a specified minimum width in order that the direction of the main magnetic flux in the steel tape will be longitudinal. For practical recording purposes, the tape must be magnetized in a lengthwise direction.

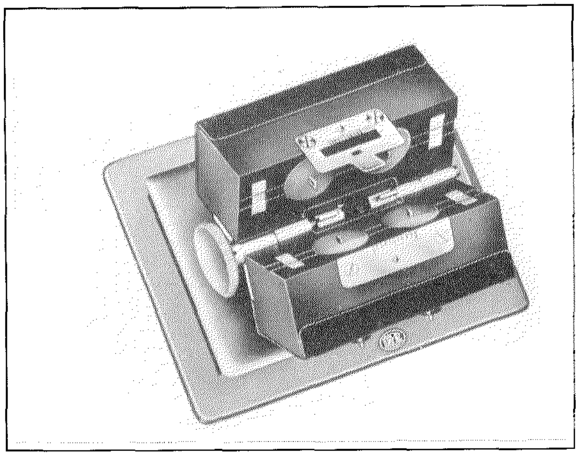

Fig. 8a—Erasing and Recording Heads.

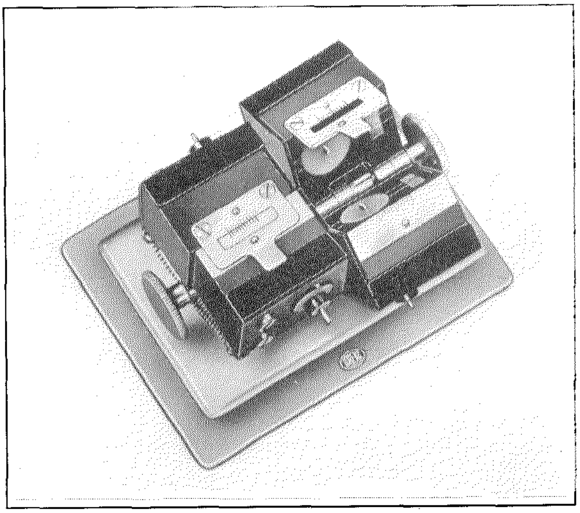

Fig. 8b—Reproduction Heads.

Since the fundamental relations involved in recording have been described, it will be necessary to consider the influence of the stray flux. It will be desirable first to return to the phenomena involved in erasing the record from the tape. When under the influence of the erasure cores, the steel tape is magnetized to the point S on the magnetization curve (Fig. 10). After a cross-sectional element of the steel tape passes from the zone of influence of the primary flux to that of the secondary flux, magnetization falls from the point R to R_1 and finally through counter magnetization reaches R_1'. The location of the point R_1 on the magnetization curve is dependent on the erasing magnetic flux. In the most unfavorable case R_1 may fall to a very low point on the straight portion of the magnetization curve. By careful determination of the magnetizing flux of the erasing cores, however, the influence of the stray flux need not be disturbing even though a small portion of the upper branch of the magnetization curve no longer serves a useful purpose. In recording, however, the stray flux, compared to the useful flux, is of some importance because of its counter influence beyond the point at which recording takes place. For this reason the direct current magnetization of the steel tape and, similarly, the maximum amplitude of the alternating speech flux relative to the straight portion of the magnetization curve must be kept small in order to prevent an undue increase in stray flux resulting from I_g+I_w. It follows, therefore, that the useful branch of the magnetization curve, rather than comprising the straight portion below R_1, is in reality considerably smaller. It should be noted also that, even though the recording current remains uniform in amplitude with increasing frequency, the amplitude of the flux induced in the tape decreases as a result of demagnetization phenomena, which will not be discussed herein.

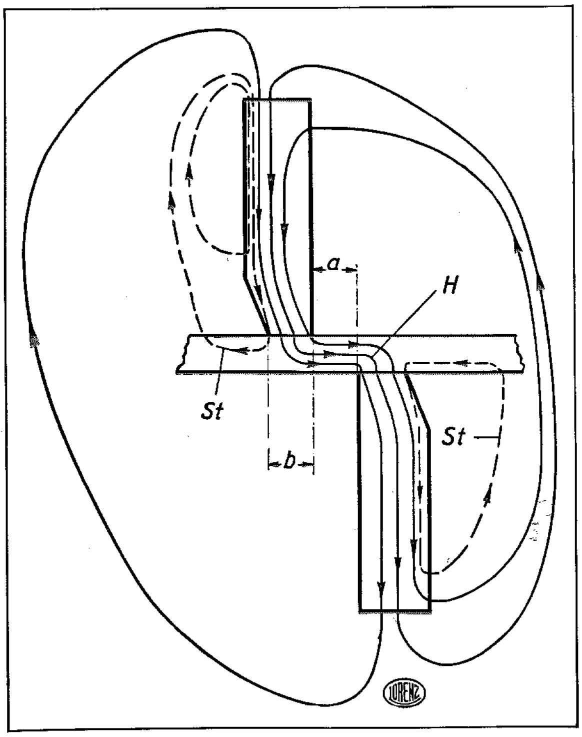

Fig. 9—Magnetic Flux in Cores and Steel Tape.

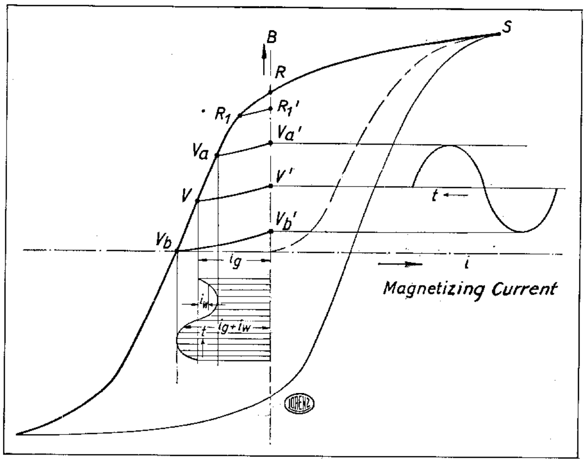

Fig. 10—Magnetization Curve Illustrating Phenomena Involved in Erasing and Recording.

Reproduction

In reproduction, the longitudinal flux emanating from the flat surface of the steel tape may be represented by

$$\Phi_a = \frac{d\Phi_i}{dl}, \tag{4}$$

where Φ_i is the flux in a cross-section of the tape during pick-up. To simplify the description, it will be assumed that only a single magnetic core is associated with the steel tape. As soon as the core touches the steel tape the flux distribution, instead of remaining symmetrical with respect to the longitudinal axis of the tape, changes in accordance with Fig. 11, the flux density on the core side increasing. For the present purpose, however, this unsymmetrical flux distribution will be disregarded. As indicated in the illustration, the flux lines from the steel tape flow completely or partially through the core. If, however, it be assumed that all lines flow entirely through the core, the equation of flux in the core may be written:

$$\Phi_k=\tfrac{1}{2}\int_{l-\frac{b}{2}}^{l+\frac{b}{2}}\Phi_a dl=\tfrac{1}{2}\int_{l-\frac{b}{2}}^{l+\frac{b}{2}}d\Phi_i. \qquad (5)$$

When the steel tape contacts the core, the magnetizing force becomes

$$U=\alpha\frac{d\Phi_k}{dt}=\tfrac{1}{2}\alpha\frac{d}{dt}\int_{l-\frac{b}{2}}^{l+\frac{b}{2}}d\Phi_i, \qquad (6)$$

where α is a constant depending on the coil winding.

If the induced flux in the steel tape changes sinusoidally, we may write:

$$\Phi_i=\Phi_{\max}\cdot\sin\omega t, \qquad (7)$$

provided the recording and reproduction tape speeds are the same. To solve equation (6), integration within limits in terms of time is necessary:

$$U=\tfrac{1}{2}\alpha\cdot\omega\cdot\Phi_{\max}\cdot\frac{d}{dt}\int_{t-\frac{k_0T}{2}}^{t+\frac{k_0T}{2}}\cos\omega t dt, \qquad (8)$$

where T is the inverse of the frequency of the wavelength λ and $k_0=b/\lambda$. In solving equation (8) we obtain the magnetizing force:

$$U_1=\alpha\cdot\Phi_{\max}\cdot\omega\cdot\sin k_0\pi\cdot\sin\omega t, \qquad (8a)$$

and the effective magnetizing force:

$$U=\frac{\alpha}{\sqrt{2}}\Phi_{\max}\cdot\omega\cdot\sin k_0\pi. \qquad (9)$$

U equals zero when $\sin k_0\pi=0$, also when $k_0=0$ or 1 or an integral multiple of π. That is, $k_0=0$ when the ratio of the core width to the wavelength becomes negligible or, in other words, when the recording flux frequency equals zero. $k_0=1_0$ when the width of the core equals the wavelength, that is, when the lines of flux are closed within the core. Sin $k_0\pi$ is maximum when $k_0=\frac{1}{2}$, that is, when the width of the core equals one-half a wavelength.

With decreasing wavelengths recorded on the steel tape, the paths of the flux in the core become shorter and, correspondingly, a smaller part of the coil is enclosed by the flux (Fig. 12). The above equations, therefore, require modification to meet actual conditions. Furthermore, it has been assumed that $\Phi_{\max}$ is constant for all frequencies, whereas in reality the magnetic amplitude decreases with increasing frequency. Experimental results check with this exposition.

Measurements show that the double core arrangement results in appreciable improvement. As previously mentioned, theoretical computations become much more involved for the case of the double core as compared with the single core. Certain controlling considerations are: With the double core, the reluctance of the magnetic circuit is considerably decreased and the efficiency is thus increased; furthermore, association of the two cores produces a certain addition of the magnetizing forces, depending on the phase relations, and also gives more satisfactory general results.

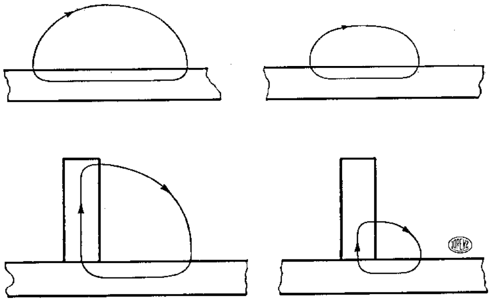

Fig. 11—Flux Distribution.

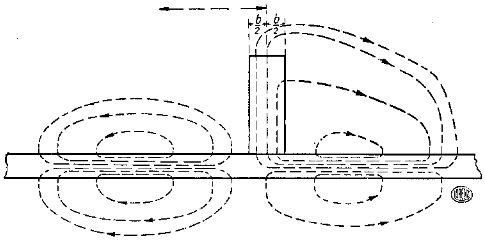

Fig. 12—Flux Distribution.

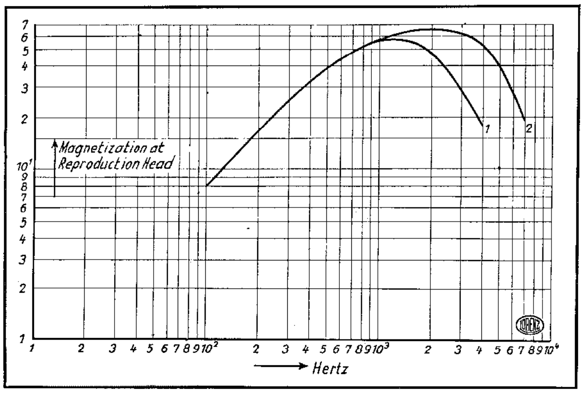

Fig. 13—Frequency Curves with Double Core Working.

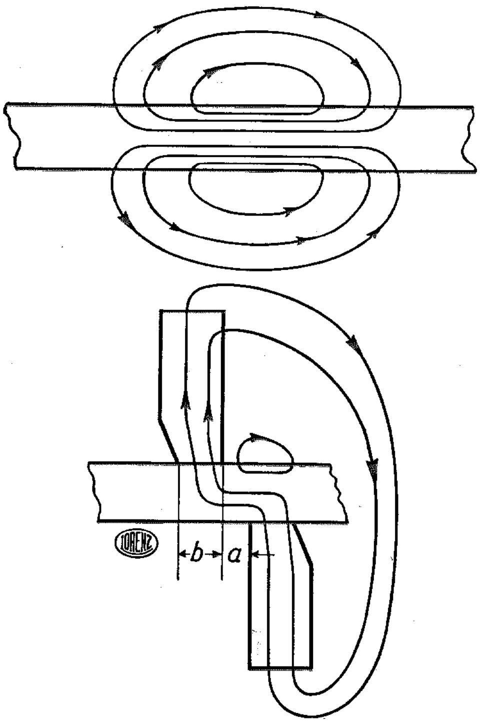

Fig. 14—Illustrating Increased Flux Obtained with Two Cores.

Fig. 13 shows the frequency curve for two core recording. Off-setting the cores is important, as already pointed out. As long as the sum of "*a*" and "*b*" (Fig. 14) is smaller than one-half the recording wavelength, the flux in both cores increases. With smaller areas of core contact and decreased lateral spacing between the cores, the high frequency characteristics of the mechanism are improved (Fig. 13). To procure a straight line frequency curve in the case of recording and reproduction, or both, simultaneous distortion corrective devices can be utilized. Practically straight line frequency curves can thus be obtained between 70–5500 Hz, which experience shows amply meet the requirements.

As in the case of disk and film reproduction, electromagnetic reproduction gives rise to inherent noise effects. Those extending over the entire frequency range are occasioned by magnetic inequalities and mechanical oscillations. The latter result from reactions between the steel tape and the cores, and are greatest at frequencies corresponding to the natural core frequencies, which may be between 4000–7000 Hz. Inasmuch as the dimensions of the parts involved cannot be identical, these frequencies result in difference and summation tones. However, in the case of electromagnetic reproduction, it is possible by suitable design to reduce the noise effects so that the ratio of the maximum to the disturbing amplitude is 85 : 1.

The new Steel Tone Tape machine has found many practical applications. For example, trials by the Reichsrundfunk-Gesellschaft, such as in trains in Hamburg, in underground tramways, and in automobiles (Fig. 15) were entirely satisfactory, and were made possible largely through technical developments of the last few years. In addition to its use in the radio and reportorial fields, electromagnetic tone recording and reproduction in the future will be applied to the solution of many problems which heretofore could not be successfully attacked because of the fact that the machine was not fully developed. Today, however, investigation of certain difficult problems can be resumed with reasonable expectation of achieving satisfactory results.

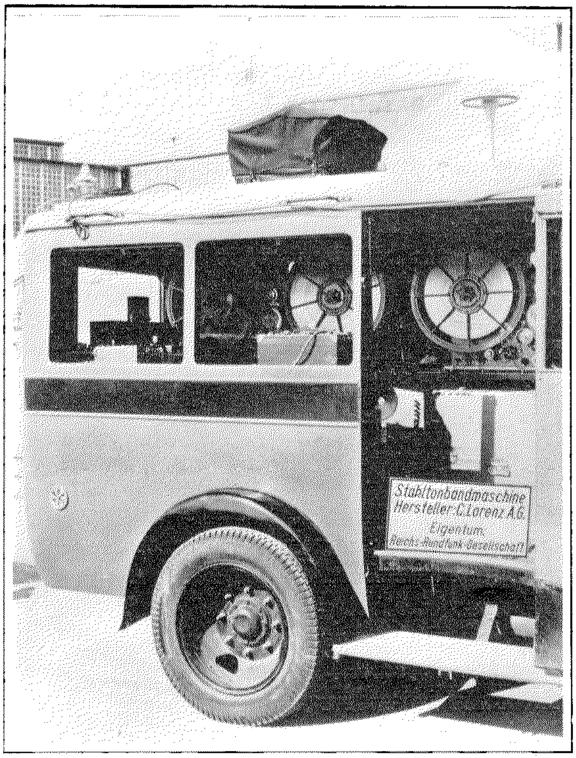

Fig. 15—Lorenz Steel Tone Tape Machine of the Reichsrundfunk-Gesellschaft.

A Discussion of Methods Employed in Calculations of Electromagnetic Fields of Radiating Conductors

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THERE are two procedures for caluclating the electromagnetic field in the neighborhood of a radiating conductor. One procedure is based on the use of the so-called Vector and Scalar potentials and the other, on the solution obtained by Heinrich Hertz for the field of a small dipole.

The first of these two methods has been used in a number of recent investigations on the interaction between radiating conductors. It is well adapted for calculating the electromagnetic field surrounding a linear radiator a half-wave or a number of half-wave lengths long wherein the current is assumed to be distributed in the form of a complete standing wave. Indeed, it will be shown later that this method applies to all radiating systems which are complete in themselves and in which no current either enters or leaves the radiating conductor. This requirement, that no current shall enter or leave the conductor, is tacitly assumed in the derivation of the formulae with which calculations by the first method are made, and constitutes the most serious limitation of the Vector-Scalar potential method. In fact, it is not applicable to terminated radiators now frequently made use of in high frequency transmitting as well as receiving antennae because large amounts of current must both enter and leave such radiators—a condition which violates the basic assumption made in the derivation of the method itself.

The second method, while somewhat more laborious and perhaps not quite as clean cut, is entirely free from this limitation. For this reason, despite being restricted, at least in its simplest form, to conductors with axial symmetry, it is suited for calculations of fields surrounding almost every type of radiator met with in practice.

While the second of these two methods is somewhat older than the first, it has not been applied in recent literature as much as it perhaps deserves to be. It, therefore, seems worth while to describe it in some detail, showing how it may be applied to terminated, as well as unterminated radiating conductors, and to compare the results obtained by this method with those obtained by the first, both when they should agree and when they should disagree because of the failure of the first method.

In view of the fact that the limitation of the first method referred to above is not generally mentioned in the literature, it appears advisable to include a somewhat detailed discussion of this subject.

I. The Second Method

As already mentioned, the second method is based on the solution for the field due to a small dipole. This solution, being a rigorous one, satisfies Maxwell's equations, as well as the boundary conditions, and may be made to serve as an elementary solution. Because of linearity of Maxwell's equations the sum of several solutions is also a solution. Consequently, if a radiating conductor could be broken up into a system of infinitesimal dipoles and the fields due to each of these dipoles were known, the total field could be obtained by addition or integration of the elementary fields. This very procedure with minor modifications will be employed for obtaining the field due to a radiating linear conductor.

Because of axial symmetry, it is convenient in these calculations to use cylindrical coordinates. Let Z_0 in Fig. 1 be the distance measured along the wire AB from A to some point D on the wire. Let ρ be the perpendicular distance from some point P in space to the wire or its continuation. Let Z be the distance from point A to the base of ρ, and Θ be the angle measured around the wire in counterclockwise direction from some arbitrary fixed plane through the wire. Let H_Θ, E_Z, and E_ρ be, respectively, the Θ component of

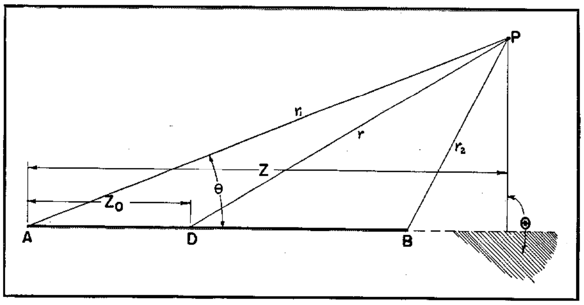

Fig. 1

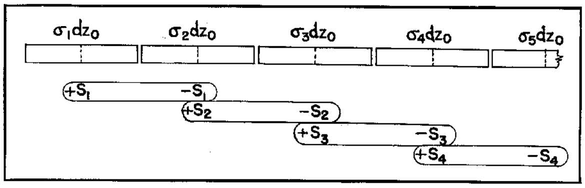

Fig. 2

the magnetic field, and the Z and the ρ components of the electric field. Then, if at some point D along the conductor AB, there is a dipole of moment $F(t)$ oriented so that its axis coincides with AB, the various components of the electric and magnetic fields produced by it at P are given by the following equations due to Hertz:

$$H_\Theta=\frac{1}{\rho}\frac{1}{C}\frac{\delta Q}{\delta t}, \tag{1}$$

$$E_Z=\frac{1}{\rho}\frac{\delta Q}{\delta \rho}, \tag{2}$$

$$E_\rho=-\frac{1}{\rho}\frac{\delta Q}{\delta Z}, \tag{3}$$

$$Q=\rho\frac{\delta}{\delta\rho}\frac{F\left(t-\frac{r}{C}\right)}{r}, \tag{4}$$

where $r=PD$, C is the velocity of light and t is the time. The Θ component of the electric field and the Z and ρ components of the magnetic field are equal to zero.

Any given charge distribution along conductor AB may be replaced by a suitable system of dipoles. Thus, for example, let $\sigma_1 dZ_0$, $\sigma_2 dZ_0, \cdots$ (Fig. 2) be the charges on the successive elements dZ_0 of the conductor. We may obviously put:

$$\sigma_1 dZ_0=S_1,$$
$$\sigma_2 dZ_0=S_2-S_1,$$
$$\sigma_3 dZ_0=S_3-S_2, \text{ etc.}$$

Then charges S_1 and $-S_1$, S_2 and $-S_2$, etc., may be considered as charges on the opposite ends of dipoles of moments S_1dZ_0, S_2dZ_0, etc. We have in general

$$\sigma dZ_0=\frac{\delta S}{\delta Z_0}dZ_0,$$

$$\sigma=\frac{\delta S}{\delta Z_0} \tag{5}$$

and hence

$$S=\int\sigma\delta Z_0+N(t). \tag{6}$$

In this equation for S, $N(t)$ is as yet an arbitrary function of t. This arbitrary function appeared in the expression for S because it is possible to add or subtract a distribution of dipoles of equal strength along the wire without in any way disturbing the value of σ except at the ends of the wire. The value of this function may be found in each particular case from the boundary conditions of the problem.

Having replaced the given current distribution by a system of dipoles of moments SdZ_0, we may calculate the components of the electromagnetic field due to a typical dipole SdZ_0 and then obtain the total field by integration. Equations (1), (2), (3), and (4) give the components of the electromagnetic field due to a dipole of moment $F(t)$. Consequently, if in these equations, we replace $F(t)$ by SdZ_0, we shall have the components of the electromagnetic field due to SdZ_0. Thus, for example, the Θ component of the magnetic field due to SdZ_0 is

$$dH_\Theta=\frac{1}{\rho}\frac{1}{C}\frac{\delta}{\delta t}(dQ), \tag{7}$$

where

$$dQ=\rho\frac{\delta}{\delta\rho}\left(\frac{\bar{S}dZ_0}{r}\right). \tag{8}$$

In this equation $\bar{S}$ is equal to S in which t has been replaced by $\left(t-\frac{r}{C}\right)$.

The total magnetic field due to the system of dipoles is given by

$$H_\Theta=\int_A^B dH_\Theta=\int_A^B\frac{1}{\rho}\frac{1}{C}\frac{\delta}{\delta t}(dQ)=\frac{1}{\rho}\frac{1}{C}\frac{\delta}{\delta t}\int_A^B dQ;$$

that is,

$$H_\Theta=\frac{1}{\rho}\frac{1}{C}\frac{\delta Q}{\delta t}, \tag{9}$$

where

$$Q=\rho\frac{\delta}{\delta\rho}\int_A^B\frac{\bar{S}dZ_0}{r}. \tag{10}$$

The above transformations are allowable since the integration is performed with respect to Z_0 which is entirely independent of the coordinates ρ and Z of a point P in space.

What has been said with respect to H_Θ is, of course, directly applicable to the other components of the electromagnetic field. Thus we find that our system of dipoles produces the following electromagnetic field:

$$H_\Theta=\frac{1}{\rho}\frac{1}{C}\frac{\delta Q}{\delta t}, \tag{11}$$

$$E_Z=\frac{1}{\rho}\frac{\delta Q}{\delta \rho}, \tag{12}$$

$$E_\rho=-\frac{1}{\rho}\frac{\delta Q}{\delta Z} \tag{13}$$

where

$$Q=\rho\frac{\delta}{\delta\rho}\int_A^B\frac{\bar{S}dZ_0}{r}. \tag{14}$$

Here $\bar{S}$ has the same meaning as in (8).

When the distribution of charges on the wire propagates with velocity of light C and without distortion of form, the auxiliary quantity Q may be evaluated with comparative ease. Indeed, let us assume that

$$S(t,\,Z_0)=S\left(t-\frac{Z_0}{C}\right);$$

then

$$Q=\rho\frac{\delta}{\delta\rho}\int_A^B\frac{S\left(t-\frac{r}{C}-\frac{Z_0}{C}\right)}{r}dZ_0.$$

If we put

$$u=t-\frac{r}{C}-\frac{Z_0}{C}$$

$$du=\frac{1}{C}\left(\frac{Z-Z_0}{r}-1\right)dZ_0,$$

we have

$$Q=\rho\frac{\delta}{\delta\rho}\int_{u_1}^{u_2}\frac{CS(u)}{Z-Z_0-r}du$$

or

$$Q=\rho\frac{\delta}{\delta\rho}\int_{u_1}^{u_2}\frac{CS(u)}{Z+(u-t)C}du.$$

In the last equation for Q, there are no quantities under the integral sign which depend on ρ. Consequently, the derivative with respect to ρ may be obtained by merely differentiating the limits; hence,

$$Q=\rho\left\{\frac{\delta u_2}{\delta\rho}\frac{CS(u_2)}{Z+(u_2-t)C}-\frac{\delta u_1}{\delta\rho}\frac{CS(u_1)}{Z+(u_1-t)C}\right\}.$$

If at A

$$Z_0=0\quad\text{and at } B\quad Z_0=l,$$

we have

$$u_2=t-\frac{r_2}{C}-\frac{l}{C},\qquad u_1=t-\frac{r_1}{C},$$

$$\frac{\delta u_2}{\delta\rho}=\frac{1}{C}\frac{\rho}{r_2},\qquad \frac{\delta u_1}{\delta\rho}=\frac{1}{C}\frac{\rho}{r_1},$$

so that

$$Q=\frac{\rho^2}{r_2}\frac{S\left(t-\frac{r_2}{C}-\frac{l}{C}\right)}{Z-r_2-l}-\frac{\rho^2}{r_1}\frac{S\left(t-\frac{r_1}{C}\right)}{Z-r_1}.$$

Since

$$(Z-r_1)(Z+r_1)=Z^2-r_1^2=-\rho^2,$$
$$(Z-l-r_2)(Z-l+r_2)=(Z-l)^2-r_2^2=-\rho^2,$$

it follows that

$$Q=S\left(t-\frac{r_1}{C}\right)\left(1+\frac{Z}{r_1}\right)-S\left(t-\frac{r_2}{C}-\frac{l}{C}\right)\left(1+\frac{Z-l}{r_2}\right). \tag{15}$$

From this value of Q the various components of the field may be obtained by differentiations in accordance with (11), (12), and (13). For example, the Θ component of the magnetic field is thus found to be

$$H_\Theta=\frac{S'\left(t-\frac{r_1}{C}\right)}{C\rho}\left(1+\frac{Z}{r_1}\right)-\frac{S'\left(t-\frac{r_2}{C}-\frac{l}{C}\right)}{C\rho}\left(1+\frac{Z-l}{r_2}\right), \tag{16}$$

where

$$S'\left(t-\frac{r_1}{C}\right)=\frac{\delta}{\delta t}S\left(t-\frac{r_1}{C}\right),$$

$$S'\left(t-\frac{r_2}{C}-\frac{l}{C}\right)=\frac{\delta}{\delta t}S\left(t-\frac{r_2}{C}-\frac{l}{C}\right).$$

As equation (16) is of some interest, we will examine it in some detail. Let us, first, convince ourselves that H_Θ as given in (16) satisfies the various boundary conditions.

When $\rho\to 0$ and $Z>l$ or $Z<0$, that is, along the continuations of the wire in either direction, H_Θ should vanish. This it does. In fact for $Z<0$ and $\rho\to 0$, we have

$$\left(1+\frac{Z}{r_1}\right)\to 0,$$

$$\left(1+\frac{Z-l}{r_2}\right)\to 0;$$

moreover as $\rho \rightarrow 0$,

$$\frac{1}{\rho}\left(1+\frac{Z}{r_1}\right) \rightarrow 0,$$

since the quantity in the parenthesis approaches zero as ρ^2. This may be made more apparent by putting

$$\rho = r_1 \sin \theta;$$

then

$$1+\frac{Z}{r_1} = 1-\cos \theta,$$

so that

$$\frac{1}{\rho}\left(1+\frac{Z}{r_1}\right) = \frac{1}{r_1} \frac{\sin^2 \theta/2}{\sin \theta/2 \cos \theta/2}.$$

This obviously approaches zero when $\theta \rightarrow 0$. In a similar manner, it may be shown also that

$$\frac{1}{\rho}\left(1+\frac{Z-l}{r_2}\right) \rightarrow 0$$

when $\rho \rightarrow 0$. Consequently, $H_\Theta \rightarrow 0$ when $\rho \rightarrow 0$ and $Z<0$.

When $Z>l$ and $\rho \rightarrow 0$,

$$\left(1+\frac{Z}{r_1}\right) \rightarrow 2, \qquad \left(1+\frac{Z-l}{r_2}\right) \rightarrow 2$$

and

$$\frac{r_2}{C}+\frac{l}{C} \rightarrow \frac{r_1}{C}.$$

Moreover all of the following quantities,

$$\epsilon_1 = 1+\frac{Z}{r_1}-2,$$

$$\epsilon_2 = 1+\frac{Z-l}{r_2}-2,$$

$$\epsilon_3 = \frac{r_2+l}{C}-\frac{r_1}{C},$$

are of order ρ^2. Consequently, for very small values of ρ, we may write

$$\epsilon_1 = a\rho^2, \qquad \epsilon_2 = b\rho^2, \qquad \epsilon_3 = d\rho^2,$$

where a, b and d are all finite. Introducing these quantities into (16), we find

$$\begin{aligned} H_\Theta &= \frac{S'\left(t-\frac{r_1}{C}\right)}{C\rho}(2+a\rho^2) - \frac{S'\left(t-\frac{r_1}{C}-d\rho^2\right)}{C\rho}(2+b\rho^2) \\ &= \frac{2}{C}\left[\frac{S'\left(t-\frac{r_1}{C}\right)-S'\left(t-\frac{r_1}{C}-d\rho^2\right)}{\rho}\right] \\ &\qquad + \left[a\rho S'\left(t-\frac{r_1}{C}\right)-b\rho S'\left(t-\frac{r_1}{C}-d\rho^2\right)\right]. \end{aligned}$$

Now, if the derivative of $S'\left(t-\frac{r_1}{C}\right)$ is finite, we have

$$S'\left(t-\frac{r_1}{C}\right)-S'\left(t-\frac{r_1}{C}-d\rho^2\right) = -d\frac{\delta S'}{\delta t}\rho^2,$$

so that

$$H_\Theta = \frac{2}{C}\rho d\frac{\delta S'}{\delta t}+\rho\left[aS'\left(t-\frac{r_1}{C}\right)-bS'\left(t-\frac{r_1}{C}-\rho^2 d\right)\right].$$

This expression obviously approaches zero when $\rho \rightarrow 0$.

Next we must examine the behavior of H_Θ near the wire. When $\rho \rightarrow 0$ and $0<Z<l$, H_Θ reduces to

$$H_\Theta = \frac{2S'\left(t-\frac{Z_0}{C}\right)}{C\rho}. \tag{17}$$

This would be exactly what we should expect if $S'\left(t-\frac{Z_0}{C}\right)$ were equal to the current at the particular value of Z_0. Let us show that this is the case provided we neglect the derivative of the arbitrary function which occurs in (6). From the equation of continuity which must always hold along any conductor we have

$$\operatorname{div} i+\frac{\delta\sigma}{\delta t} = 0. \tag{E) *$$

Since we are dealing with only one dimension, this reduces to

$$\frac{\delta i}{\delta Z_0}+\frac{\delta\sigma}{\delta t} = 0; \tag{18}$$

Consequently,

$$i = -\int\frac{\delta\sigma}{\delta t}\,dZ_0 = -\frac{\delta}{\delta t}\int\sigma dZ_0.$$

In view of (6) we may also write

$$i = -\frac{\delta S}{\delta t}+\frac{\delta N(t)}{\delta t} = -S'\left(t-\frac{Z_0}{C}\right)+\frac{\delta N(t)}{\delta t}.$$

Hence $i=-S'$ when $\delta N(t)/\delta t=0$. The minus sign before S' has no particular significance as far as (17) is concerned because this sign merely has to do with the sense of H_0. From the above discussion, it may be concluded that the boundary conditions are satisfied only if $\delta N(t)/\delta t=0$; that is, only if $N(t)=$ a constant. Then and only then does

$$H_\Theta = -\frac{2i}{C\rho}$$

near the wire, as should be the case.

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* See page 84, equation (e).

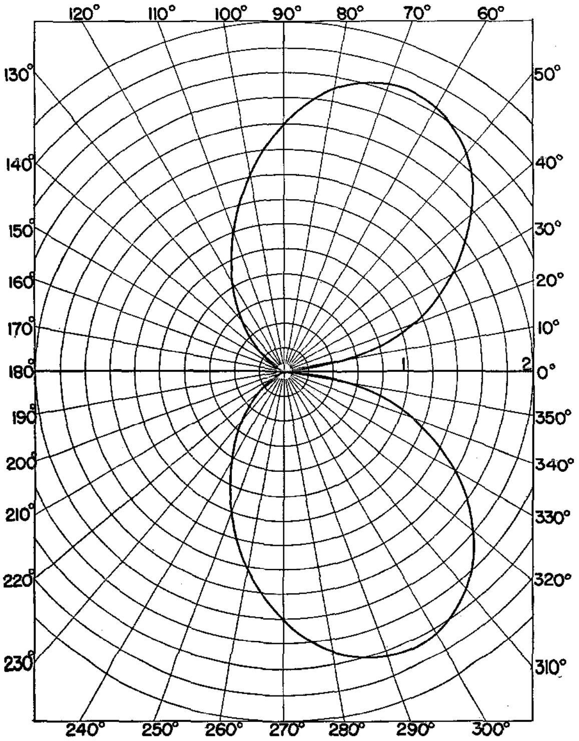

Fig. 3

So far, we have examined the behavior of H_Θ near the wire. We now wish to inquire what happens to H_Θ at a great distance from the wire. When r_1 is assumed to be very large, the following equations hold (see Fig. 1):

$$\frac{Z}{r_1}=\frac{Z-l}{r_2}=\cos\theta,$$

$$\rho=r_1\sin\theta,$$

$$r_1-r_2=l\cos\theta$$

and

$$H_{\Theta\infty}=\frac{1}{r_1 C}\cot\frac{\theta}{2}\left\{S'\left(t-\frac{r_1}{C}\right)-S'\left[\left(t-\frac{r_1}{C}\right)-\frac{l}{C}(1-\cos\theta)\right]\right\}. \qquad (19)$$

From this equation, it is clear that when $r_1\rightarrow\infty$, $H_{\Theta\infty}\rightarrow 0$. The same relations obtain, even when $\theta=0$ or 180°; for, as we have already seen, $H_\Theta=0$ along the continuations of the wire for any value of r_1.

Before leaving H_Θ, it may be well to point out that equations (16) and (19) hold good regardless of the shape of the current wave as long as this wave propagates with the velocity of light and without distortion. For example, these equations should be useful in calculations of magnetic fields produced by lightning surges traveling along power transmission lines, as well as in the studies of radiation fields of terminated antennae with sinusoidal current distributions.

We shall now derive an expression for E_Z. This expression may be obtained from (15) by performing the differentiation indicated in (12). Since

$$\frac{\delta}{\delta\rho}S\left(t-\frac{r_1}{C}\right)=-S'\left(t-\frac{r_1}{C}\right)\frac{\rho}{Cr_1},$$

$$\frac{\delta}{\delta\rho}S\left(t-\frac{r_2}{C}-\frac{l}{C}\right)=-S'\left(t-\frac{r_2}{C}-\frac{l}{C}\right)\frac{\rho}{Cr_2},$$

we have

$$\begin{aligned}E_Z=&-\frac{S'\left(t-\frac{r_1}{C}\right)}{Cr_1}\left(1+\frac{Z}{r_1}\right)\\&+\frac{S'\left(t-\frac{r_2}{C}-\frac{l}{C}\right)}{Cr_2}\left(1+\frac{Z-l}{r_2}\right)\\&-S\left(t-\frac{r_1}{C}\right)\frac{Z}{r_1^3}+S\left(t-\frac{r_2}{C}-\frac{l}{C}\right)\frac{Z-l}{r_2^3}.\end{aligned} \qquad (20)$$

It is quite apparent from this equation that the electric field is made up of two parts: The first part is in the nature of a radiation field which varies roughly as $1/r$. The second part is a purely electrostatic field, due to charges at the ends of the wire.

Equation (20) enables us to learn a little more regarding the physical nature of $N(t)$ which first occurred in (6) and which was later shown to be a

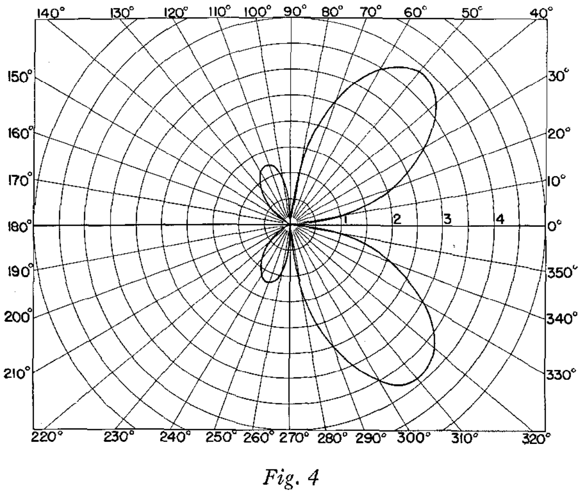

Fig. 4

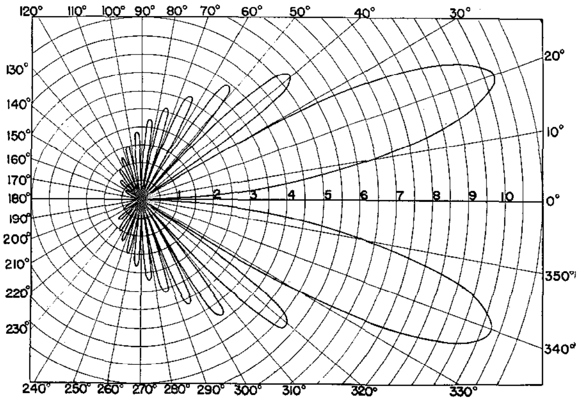

Fig. 5

constant. Indeed, by adding a constant N to S in (20), we add

$$e_Z = -N\frac{Z}{r_1^3} + N\frac{Z-l}{r_2^3}$$

to E_Z. The first term in e_Z is obviously the Z component of the $1/r^2$ field due to charge $+N$ at $Z=0$. Similarly, the second term in e_Z is due to charge $-N$ at $Z=l$. When we are dealing with a purely alternating distribution of current, we must be careful to select S in such a manner that it contains no terms which are independent of time. This may be done by adding a proper value of N. In general, the choice of N presents little difficulty as long as its physical nature and its origin are kept in mind.

A case of considerable practical interest to radio engineers is obtained by putting

$$i = i_0 \sin \omega\left(t - \frac{Z_0}{C}\right).$$

This is roughly the distribution of current actually obtained in the so-called "terminated antennae" (Rhombic antennae, Beverage antennae, etc.). In these antennae the wires are terminated into their surge impedances so that current waves are not reflected from the end. When

$$i = i_0 \sin \omega\left(t - \frac{Z_0}{C}\right),$$

we have

$$S' = i = i_0 \sin \omega\left(t - \frac{Z_0}{C}\right)$$

$$S = -\frac{i_0}{\omega}\cos \omega\left(t - \frac{Z_0}{C}\right) + c$$

$$c = 0.$$

From (16)

$$H_\Theta = \frac{i_0}{C\rho} \sin \omega\left(t - \frac{r_1}{C}\right)\left(1 + \frac{Z}{r_1}\right) - \frac{i_0}{\rho C} \sin \omega\left(t - \frac{r_2}{C} - \frac{l}{C}\right)\left(1 + \frac{Z-l}{r_2}\right). \quad (21)$$

From (19), for very large values of r,

$$H_{\Theta\infty} = \frac{2i_0}{Cr_1} \cot\frac{\theta}{2} \sin\left[\frac{\omega l}{2C}(1 - \cos\theta)\right] \cos\left[\omega\left(t - \frac{r_1}{C}\right) - \frac{\omega l}{2C}(1 - \cos\theta)\right]. \quad (22)$$

From (20)

$$E_Z = -\frac{i_0 \sin \omega\left(t - \frac{r_1}{C}\right)}{Cr_1}\left(1 + \frac{Z}{r_1}\right) + \frac{i_0 \sin\left(t - \frac{r_2}{C} - \frac{l}{C}\right)}{Cr_2}\left(1 + \frac{Z-l}{r_2}\right) + \frac{i_0}{\omega}\cos \omega\left(t - \frac{r_1}{C}\right)\frac{Z}{r_1^3} - \frac{i_0}{\omega}\cos \omega\left(t - \frac{r_2}{C} - \frac{l}{C}\right)\frac{Z-l}{r_2^3}. \quad (23)$$

The amplitude of $H_{\Theta\infty}$ has been plotted against θ in Figs. 3, 4 and 5 for $l=\lambda/2$, $l=\lambda$, $l=6\lambda$. All of these figures clearly show the assymmetrical nature of radiation from terminated wires. For the sake of completeness, the angle of maximum radiation from wires of various lengths is given in Fig. 6. From this figure, incidentally, it appears that the angle of maximum radiation from a terminated wire 1/2 λ long is not 90° but 68°. For longer wires, the angles of maximum radiation approach those for unterminated wires with standing waves.[1]

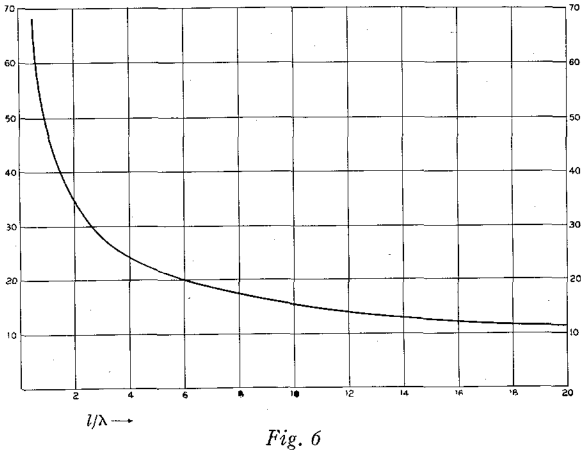

Fig. 6

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[1] See equations (28) and (29).

The power radiated by a terminated antenna may be calculated by two methods.

First Method: This method is based on the properties of the Poynting Vector. If we surround the wire by a large imaginary sphere of radius r_1 with its center at $Z=0$, the power which passes through each surface element dS of this sphere is given by

$$dP=\frac{CH_{\Theta\infty}^2}{4\pi}\,dS.$$

Since $H_{\Theta\infty}$ is constant along small circles defined by $\theta=$a constant, it is convenient to divide the whole surface into annular elements delimited by small circles which correspond to $\theta=\theta_1$ and $\theta=\theta_1+d\theta_1$. The surface of the annular region formed in this manner is

$$dS=2\pi r_1^2\sin\theta d\theta.$$

The power radiated through the annular element is

$$dP=\frac{CH_{\Theta\infty}^2}{4\pi}\,2\pi r_1^2\sin\theta d\theta.$$

Hence the total power radiated through the sphere at any given instant is given by

$$\begin{aligned}P&=\int_0^\pi\frac{CH_{\Theta\infty}^2}{4\pi}\,2\pi\sin\theta r_1^2 d\theta\\&=\frac{2i_0^2}{C}\int_0^\pi\cot^2\frac{\theta}{2}\sin^2\frac{\omega l}{2C}\,(1-\cos\theta)\\&\qquad\cos^2\left[\omega t-\frac{\omega l}{2C}(1-\cos\theta)\right]d\theta.\end{aligned}$$

The average power radiated per cycle is given by

$$\overline{P}=\frac{\omega}{2\pi}\int_0^{2\pi/\omega}Pdt;$$

that is,

$$\begin{aligned}\overline{P}=\frac{2i_0^2}{C}\int_0^\pi\frac{\omega}{2\pi}\int_0^{2\pi/\omega}&\cot^2\frac{\theta}{2}\sin^2\frac{\omega l}{2C}(1-\cos\theta)\\&\cos^2\left[\omega t-\frac{\omega l}{2C}(1-\cos\theta)\right]d\theta dt.\end{aligned}$$

By carrying out the integration with respect to t first we get

$$\overline{P}=\frac{i_0^2}{C}\int_0^\pi\cot^2\frac{\theta}{2}\sin^2\frac{\omega l}{2C}(1-\cos\theta)d\theta.$$

If we now put $u=1-\cos\theta$ and note that

$$\cot^2\frac{\theta}{2}=\frac{1+\cos\theta}{1-\cos\theta},$$

we obtain

$$\begin{aligned}\overline{P}&=\frac{i_0^2}{C}\int_0^2\left(\frac{2}{u}-1\right)\sin^2\frac{\omega l}{2C}u\,du\\&=\frac{i_0^2}{C}\int_0^2\frac{1-\cos\frac{\omega l}{C}u}{u}du-\frac{i_0^2}{C}\int_0^2\sin^2\frac{\omega l}{2C}u\,du,\end{aligned}$$

$$P=\frac{i_0^2}{C}\int_0^2\frac{1-\cos\frac{\omega l}{C}u}{u}du-\frac{i_0^2}{C}\left(1-\frac{\sin\frac{2\omega l}{C}}{\frac{2\omega l}{C}}\right).\tag{24}$$

Second Method: By putting $r_1=Z_0$, $r_2=l-Z_0$ in (23), we find that the electric field along the wire is given by

$$\begin{aligned}E_2'=-2i_0\frac{\sin\omega\left(t-\frac{Z_0}{C}\right)}{CZ_0}+\frac{i_0\cos\omega\left(t-\frac{Z_0}{C}\right)}{\omega Z_0^2}\\+i_0\frac{\cos\omega\left(t+\frac{Z_0}{C}-\frac{2l}{C}\right)}{\omega(l-Z_0)^2}.\end{aligned}$$

The drop of potential across an element dZ_0 of the wire is $E_Z'dZ_0$. Whenever current flows against a drop of potential it does work. The rate at which this work is done, that is, power, is given by the product of the in-phase components of the current and the opposing potential drop. In this case, the current is $i=i_0\sin\omega(t-Z_0/C)$ and the drop of potential opposing the current is

$$\begin{aligned}-E_Z'dZ_0=2i_0&\frac{\sin\omega\left(t-\frac{Z_0}{C}\right)}{CZ_0}dZ_0\\&-i_0\frac{\cos\omega\left(t-\frac{Z_0}{C}\right)}{\omega Z_0^2}dZ_0\\&-i_0\frac{\cos\omega\left(t-\frac{Z_0}{C}\right)\cos\frac{2\omega}{C}(l-Z_0)}{\omega(l-Z_0)^2}dZ_0\\&-i_0\frac{\sin\omega\left(t-\frac{Z_0}{C}\right)\sin\frac{2\omega}{C}(l-Z_0)}{\omega(l-Z_0)^2}dZ_0.\end{aligned}$$

The in-phase component of $-E_Z'dZ_0$ is

$$\begin{aligned}-E_Z''dZ_0=2i_0&\frac{\sin\omega\left(t-\frac{Z_0}{C}\right)}{CZ_0}\\&-i_0\frac{\sin\omega\left(t-\frac{Z_0}{C}\right)\sin\frac{2\omega}{C}(l-Z_0)}{\omega(l-Z_0)^2}dZ_0.\end{aligned}$$

Consequently, the power dissipated in dZ_0 is

$$dP=-iE_Z''dZ_0=2i_0^2\frac{\sin^2\omega\left(t-\frac{Z_0}{C}\right)}{CZ_0}dZ_0$$

$$-i_0^2\frac{\sin^2\omega\left(t-\frac{Z_0}{C}\right)\sin\frac{2\omega}{C}(l-Z_0)}{\omega(l-Z_0)^2}dZ_0.$$

The average power per cycle is

$$d\bar{P}=\frac{\omega}{2\pi}\int_0^{2\pi/\omega}dP\delta t$$

$$=\frac{i_0^2}{2}\left[\frac{2}{CZ_0}-\frac{\sin\frac{2\omega}{C}(l-Z_0)}{\omega(l-Z_0)^2}\right]dZ_0. \quad (25)$$

The power radiated by the portion of the wire included between $Z_0=\alpha$ and $Z_0=l-\alpha$ is given by

$$\bar{P}=\frac{i_0^2}{2}\int_\alpha^{l-\alpha}\frac{2}{CZ_0}dZ_0-\frac{i_0^2}{2}\int_\alpha^{l-\alpha}\frac{\sin\frac{2\omega}{C}(l-Z_0)}{\omega(l-Z_0)^2}dZ_0.$$

If in the second integral we put $l-Z_0=u$, we have

$$\bar{P}=\frac{i_0^2}{2}\int_\alpha^{l-\alpha}\frac{2}{CZ_0}dZ_0-\frac{i_0^2}{2}\int_\alpha^{l-\alpha}\frac{\sin\frac{2\omega u}{C}}{\omega u^2}du$$

or

$$\bar{P}=\frac{i_0^2}{2}\int_\alpha^{l-\alpha}\frac{2}{CZ_0}dZ_0-\frac{i_0^2}{2}\int_\alpha^{l-\alpha}\frac{2\cos\frac{2\omega}{C}u}{Cu}du$$

$$+\left.\frac{\sin\frac{2\omega u}{C}}{\omega u}\right|_\alpha^{l-\alpha}.$$

If now in the first integral we let $u=Z_0$, we may write

$$\bar{P}=\frac{i_0^2}{2}\int_\alpha^{l-\alpha}\left[\frac{2}{Cu}-\frac{2\cos\frac{2\omega}{C}u}{Cu}\right]du+\frac{i_0^2}{2}\left.\frac{\sin\frac{2\omega u}{C}}{\omega u}\right|_\alpha^{l-\alpha}.$$

When $\alpha\rightarrow 0$, this becomes

$$\bar{P}=\frac{i_0^2}{2}\int_0^l\left[\frac{2}{Cu}-\frac{2\cos\frac{2\omega}{C}u}{Cu}\right]du-\frac{i_0^2}{C}\left(1-\frac{\sin\frac{2\omega l}{C}}{\frac{2\omega l}{C}}\right);$$

or if we put

$$u=\frac{l}{2}u',$$

$$\bar{P}=\frac{i_0^2}{C}\int_0^2\frac{1-\cos\frac{\omega u'}{C}}{u'}du'-\frac{i_0^2}{C}\left(1-\frac{\sin\frac{2\omega l}{C}}{\frac{2\omega l}{C}}\right) \quad (26)$$

This is exactly the same result as the one already obtained by the previous method. Equation (26) gives the power radiated from a terminated wire in terms of the peak current i_0 and the length of the wire in wavelengths.

For convenience of discussion, we may introduce a fictitious resistance R defined as follows:

$$R\left(\frac{i_0}{\sqrt{2}}\right)^2=\bar{P}.$$

This resistance may be called the Radiation Resistance of a terminated wire.

From (26) we have

$$R=\frac{2}{C}\int_0^2\frac{1-\cos\frac{l\omega u}{C}}{u}du-\frac{2}{C}\left(1-\frac{\sin\frac{2\omega l}{C}}{\frac{2\omega l}{C}}\right).$$

If we put

$$\beta=\frac{\omega l}{C}=2\pi\frac{l}{\lambda}$$

and

$$\chi=\beta u,$$

then

$$R=\frac{2}{C}\int_0^{2\beta}\frac{1-\cos\chi}{\chi}d\chi-\frac{2}{C}\left(1-\frac{\sin 2\beta}{2\beta}\right)$$

$$=\frac{2}{C}\left[\log_e 2\beta+\operatorname{sil} 2\beta+\gamma-1+\frac{\sin 2\beta}{2\beta}\right], \quad (26A)$$

where

$$\gamma=.577\cdots.$$

In practical units, this becomes

$$R=60\left[\log_e 2\beta+\operatorname{sil} 2\beta+\gamma-1+\frac{\sin 2\beta}{2\beta}\right]\text{ ohms.} \quad (26B)$$

Fig. 7 illustrates variation of R with l/λ.

These results enable one to make some estimates of practical interest. As an example, consider a half wave antenna fed off-center by a single feeder of length L adjusted, as usual, so that it carries only traveling waves. Suppose that the average height of the feeder is $H=50'$ and that the diameter of the feeder is 0.162 inches (No. 6 A.W.G.). The surge impedance of the feeder is

$$Z_0=138\log_{10}\frac{4H}{d}=580\text{ ohms.}$$

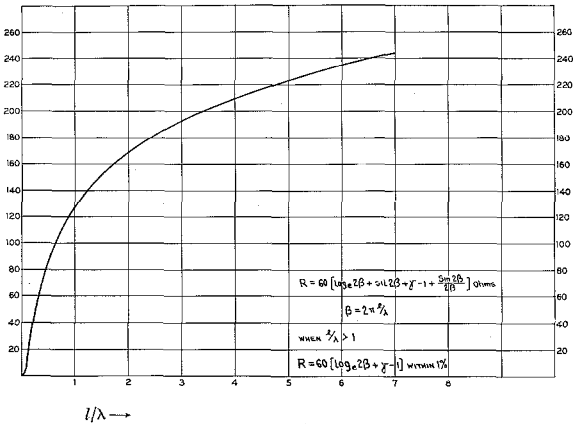

Fig. 7

Then if the R.M.S. current in the feeder is I, the power delivered to the feeder is

$$I^2 z_0 = 580 I^2 \text{ watts.}$$

On the other hand, the power radiated by the feeder is I^2R, where R is the radiation resistance of the feeder given in terms of l/λ in Fig. 7. Suppose that the feeder is 1λ long, then $R = 127$ ohms. The power delivered to the half wave is

$$z_0 I^2 - RI^2 = 463 I^2,$$

that is,

$$\frac{463}{580} = .80$$

or 80% of the power delivered to the feeder. The balance of 20% is radiated by the feeder. These calculations are admittedly rough since the image of the feeder in the ground is not taken into account. When the feeder proceeds at an angle to ground so that the major portion of the feeder is a considerable fraction of a wavelength above ground, the above calculation should be approximately correct.

Before leaving this subject, we wish to call attention to equation (25) which was used in the calculation of the total radiated power. From this equation, it appears that when Z_0 is small $d\bar{P}$ is positive and when Z_0 is large, and particularly when it is nearly equal to l, $d\bar{P}$ is negative. This means that energy is thrown into space near $Z_0 = 0$ and partially reclaimed near $Z_0 = l$. Only the balance is radiated into free space. The amount of power which is circulated between the ends of the wire is very large; in fact, in accordance with our equations, it is infinite. This infinite value, however, is entirely due to the fact that in our calculations the wire was assumed to be very thin so that E_Z'' varies as $1/Z_0$ near $Z_0 = 0$ and as $1/(l - Z_0)$ near $Z_0 = l$. In any actual case E_Z'' cannot become infinite at $Z_0 = 0$ and at $Z_0 = l$ and consequently the amount of circulating power will be finite. Since our equations for E probably become correct a small distance away from the ends, we have every reason to expect that the amount of circulating power is large in reality as well as in the idealized theory.

Let us now consider a wire which is open ended at $Z_0 = l$. In this case, there will be two wave trains: the direct wave traveling forward, and the reflected wave traveling back. The current in the forward wave is given by

$$i = i_0 \sin \omega\left(t - \frac{Z_0}{C}\right);$$

the current due to the reflected wave is

$$\begin{aligned} i' &= -i_0 \sin \omega\left(t + \frac{Z_0}{C} - \frac{2l}{C}\right) \\ &= -i_0 \sin \omega\left[\left(t - \frac{l}{C}\right) - \frac{l - Z_0}{C}\right]. \end{aligned}$$

The total current at any place along the wire is

$$I = i + i' = -2i_0 \sin \omega \frac{l - Z_0}{C} \cos \omega\left(t - \frac{l}{C}\right).$$

The amplitude of the total current thus varies sinusoidally along the wire, starting with $I = 0$ at $Z_0 = l$. The loop current is $2i_0$. The electromagnetic field produced by this distribution of current may be easily calculated from our equations for traveling waves. Indeed, the total field is simply the sum of the fields—the field due to the direct wave and the field due to the reflected wave. For example, the H_Θ component produced by the direct wave according to (21) is

$$H_\Theta = \frac{i_0 \sin \omega\left(t - \frac{r_1}{C}\right)}{\rho C}\left(1 + \frac{Z}{r_1}\right) - \frac{i_0 \sin \omega\left(t - \frac{r_2}{C} - \frac{l}{C}\right)}{\rho C}\left(1 + \frac{Z - l}{r_2}\right).$$

The H_Θ component produced by the reflected wave may be obtained from H_Θ by interchanging r_1 and r_2, also, Z and $l - Z$, and by putting

$(t-l/C)$ in place of t, and $-i_0$ in place of i_0. After carrying out these changes, we obtain

$$H_\Theta' = -\frac{i_0 \sin\omega\left(t-\frac{r_2}{C}-\frac{l}{C}\right)}{\rho C}\left(1+\frac{l-Z}{r_2}\right) + \frac{i_0 \sin\omega\left(t-\frac{r_1}{C}-\frac{2l}{C}\right)}{\rho C}\left(1-\frac{Z}{r_1}\right).$$

The total field is $h_\Theta = H_\Theta + H_\Theta'$.

In a special case when l is equal to an integral number of half waves,

$$\frac{2\omega l}{C} = 4\pi\frac{l}{\lambda} = 2\pi N; \qquad N = 1, 2, 3, \cdots,$$

$$\sin\omega\left(t-\frac{r_1}{C}-\frac{2l}{C}\right) = \sin\omega\left(t-\frac{r_1}{C}\right)$$

and

$$h_\Theta = \frac{2i_0}{\rho C}\left[\sin\omega\left(t-\frac{r_1}{C}\right) - \sin\omega\left(t-\frac{r_2}{C}-\frac{l}{C}\right)\right]$$

$$= \frac{I_0}{\rho C}\left[\sin\omega\left(t-\frac{r_1}{C}\right) - (-1)^N \sin\omega\left(t-\frac{r_2}{C}\right)\right], \quad (27)$$

where $I_0 = 2i_0$ is the loop current. This equation is one of the equations first derived by Pistolkors[2] using the Vector Potential Method. If in (27) r_1 is assumed to be very large so that

$$r_1 - r_2 = l\cos\theta,$$
$$\rho = r_1 \sin\theta,$$

the magnetic field reduces to the well known equations for the radiation field due to wires an integral number of half waves long:[3]

$$h_{\Theta\infty} = \frac{2I_0}{Cr_1}\,\frac{\sin\left(\frac{\pi}{2}N\cos\theta\right)}{\sin\theta} \qquad (28)$$

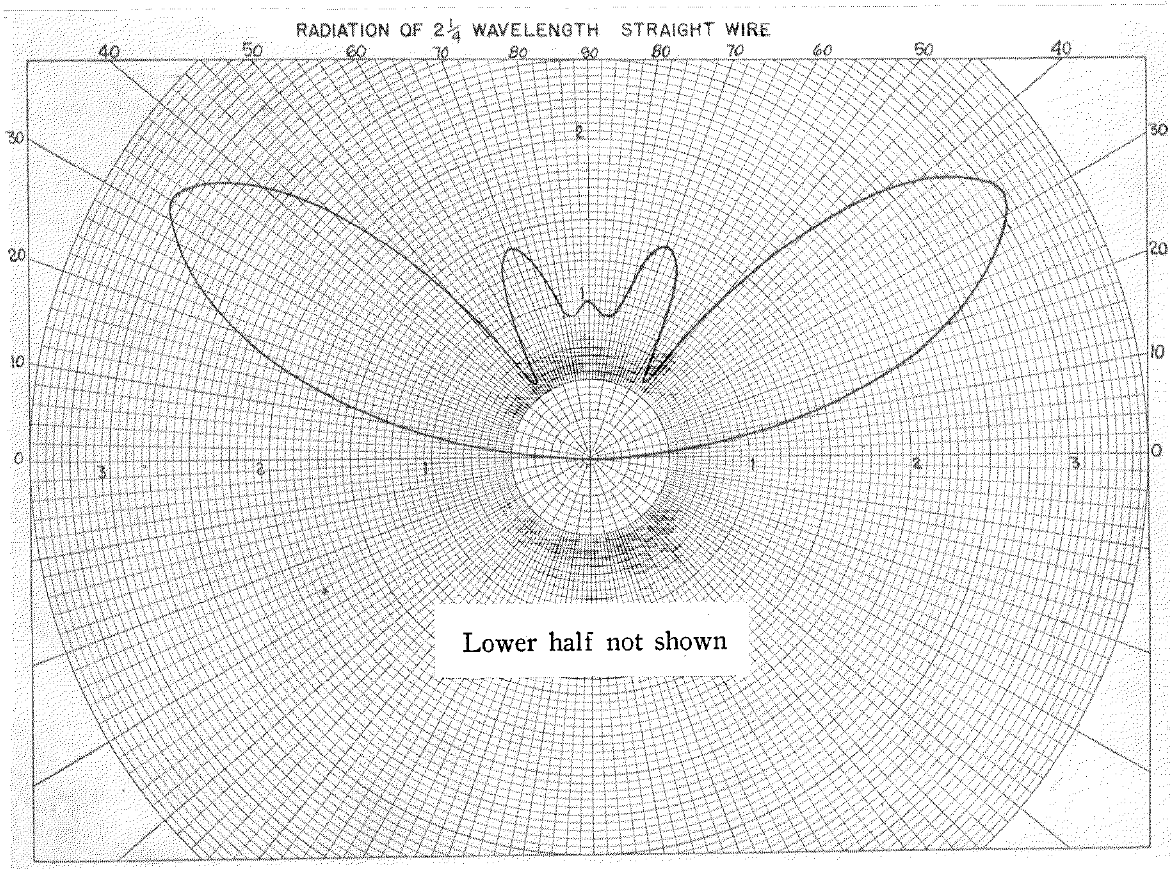

Fig. 8

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[2] "The Radiation Resistance of Beam Antennas," by A. A. Pistolkors, *Proceedings I. R. E.*, Vol. 17, No. 3, Mar. 1929, pp. 562–579.

[3] "Die electrischen Schwingungen um einen Stabförmigen Leiter, behandelt nach der Maxwell'schen Theorie," by Max Abraham, *Annalen der Physik und Chemie*, Vol. 66, No. 3, pp. 435–472, 1898, No. 11.

where $N=2, 4, \cdots$,

$$h_{\Theta\infty}=\frac{2I_0}{Cr_1}\frac{\cos\left(\frac{\pi}{2}N\cos\theta\right)}{\sin\theta}, \qquad (29)$$

where $N=1, 3, 5, \cdots$.

Other components of the electromagnetic field due to a wire with standing waves may be obtained by exactly the same method as the one employed above to obtain H_Θ.

When l is not equal to an integral number of half wavelengths but is an arbitrary length we may still write

$$h_\Theta=H_\Theta+H_\Theta'$$

and hence also

$$h_{\Theta\infty}=H_{\Theta\infty}+H_{\Theta\infty}'.$$

In this case

$$H_{\Theta\infty}=\frac{2i_0}{r_1C}\cot\frac{\theta}{2}\sin\frac{\omega l}{2C}(1-\cos\theta)$$
$$\times\cos\left[\omega\left(t-\frac{r_1}{C}\right)-\frac{l\omega}{2C}(1-\cos\theta)\right]$$

and

$$H_{\Theta\infty}'=-\frac{2i_0}{r_1C}\tan\frac{\theta}{2}\sin\frac{\omega l}{2C}(1+\cos\theta)$$
$$\times\cos\left[\omega\left(t-\frac{r_1}{C}\right)-\frac{l\omega}{C}-\frac{l\omega}{2C}(1-\cos\theta)\right].$$

From the above values of $H_{\Theta\infty}$ and $H_{\Theta\infty}'$ it is clear that in general these vectors are not in phase but out of phase by angle

$$\left(\pi-\frac{l\omega}{C}\right).$$

Hence the total field is

$$|h_{\Theta\infty}|=\sqrt{|H_{\Theta\infty}|^2+|H_{\Theta\infty}'|^2-2H_{\Theta\infty}H_{\Theta\infty}'\cos\frac{\omega l}{C}}.$$

In Figs. 8 and 9 are shown radiation diagrams of wires $2\frac{1}{4}\lambda$ and $7\frac{3}{4}\lambda$ long. Both were calculated from the above equation for $|h_{\Theta\infty}|$. Fig. 9A, for comparison, shows the radiation diagram of a wire 8λ long.

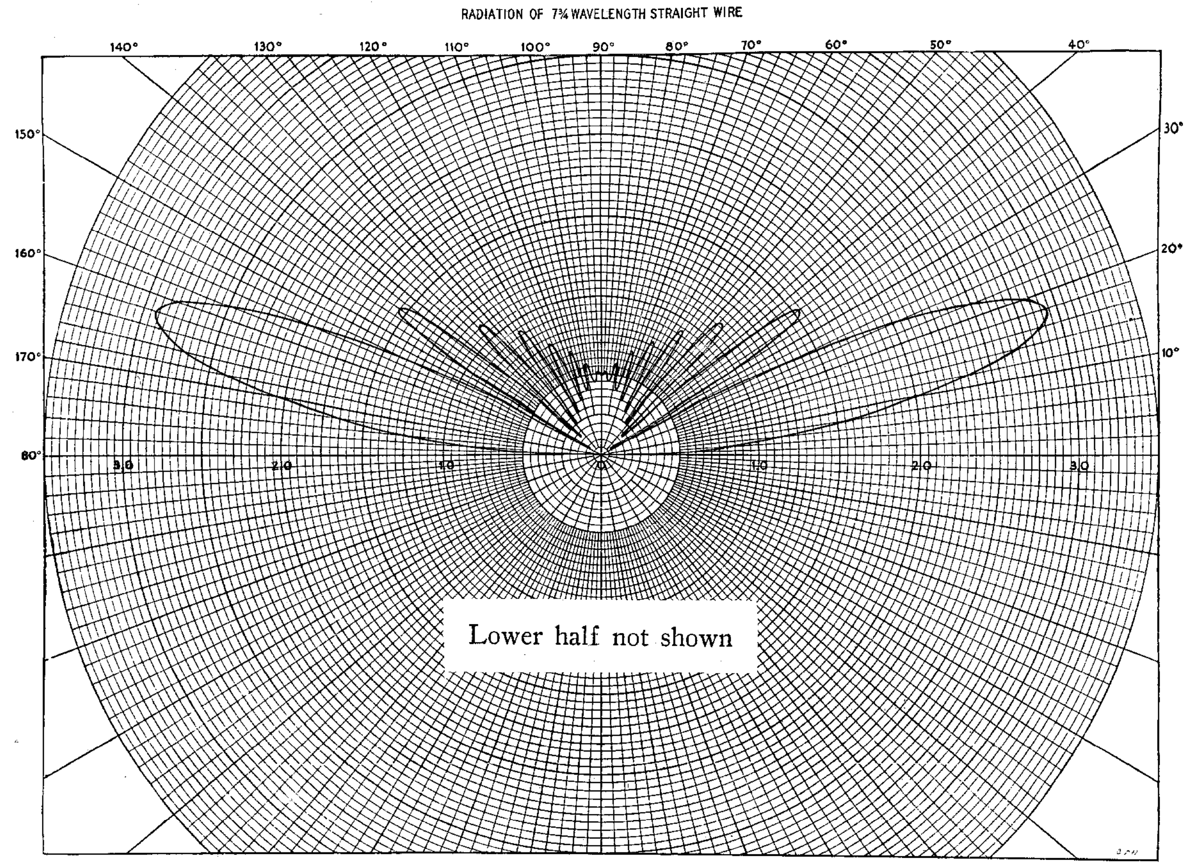


Fig. 9

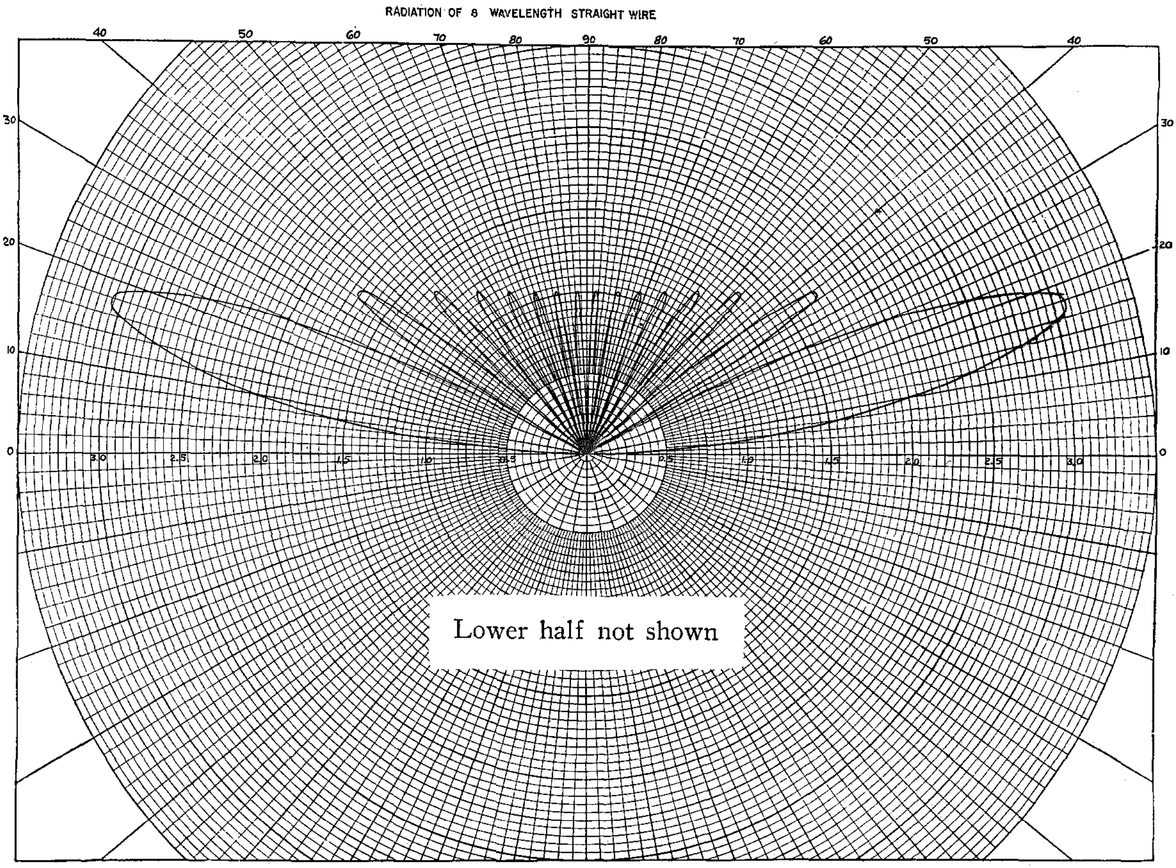


Fig. 9A

Power $\overline{P}$ radiated by a wire of length l may be obtained by the use of the Poynting theorem. This power may be represented by means of radiation resistance defined as follows:

$$\left(\frac{2i_0}{\sqrt{2}}\right)^2 R_l = \overline{P},$$

where $(2i_0/\sqrt{2})$ is the loop RMS current. After the necessary integrations are carried out it is found that

$$R_l = 30[\log_e (3.562\beta) - \sin^2 \beta + \text{sil } 2\beta] \text{ ohms},$$

where $\beta = 2\pi(l/\lambda)$. Fig. 10 shows how R_l varies with l/λ.

The following method of obtaining R_l is probably most enlightening.

Since

$$|h_{\Theta\infty}|^2 = |H_{\Theta\infty}|^2 + |H_{\Theta\infty}'|^2 - 2|H_{\Theta\infty}||H_{\Theta\infty}'| \cos \beta,$$

the average power radiated is

$$P_0 = \frac{C}{8\pi}\int_0^\pi |H_{\Theta\infty}|^2 2\pi r^2 \sin \theta d\theta$$

$$+\frac{C}{8\pi}\int_0^\pi |H_{\Theta\infty}'|^2 2\pi r^2 \sin \theta d\theta$$

$$-\frac{C}{8\pi}\int_0^\pi 2|H_{\Theta\infty}||H_{\Theta\infty}'| 2\pi r^2 \sin \theta \cos \beta d\theta$$

$$= \text{I} + \text{II} - \text{III}.$$

The first term is the power radiated by the traveling wave proceeding toward the open end. This has already been calculated. (See equations (24), (26), (26A), and (26B).) The second term is the power radiated by the reflected wave. Under the present assumption that the reflected wave is equal to the direct wave this term is obviously equal to the first term. The third term is the interaction term which gives the power dissipated by the current in the forward wave flowing against the field of the reflected wave plus the power dissipated by the current in the reflected wave flowing against the field of the forward wave. This third term is the only one which we now must calculate.

We have

$$\text{III} = \frac{i_0^2}{C}\int_0^\pi \sin\frac{\beta}{2}(1-\cos\theta)\sin\frac{\beta}{2}(1+\cos\theta) \times \sin\theta d\theta \cos\beta.$$

If we put $\cos\theta = u$

then

$$\begin{aligned}\text{III} &= 2\frac{i_0^2}{C}\int_{-1}^{+1} \sin\frac{\beta}{2}(1-u)\sin\frac{\beta}{2}(1+u)\cos\beta du\\ &= \frac{i_0^2}{C}\int_{-1}^{+1}(\cos\beta u - \cos\beta)\cos\beta du\\ &= 2\frac{i_0^2}{C}\left(\frac{\sin 2\beta}{2\beta} - \cos^2\beta\right).\end{aligned}$$

Now from (26A)

$$\text{I}+\text{II} = 2\frac{i_0^2}{C}\left(\log_e 2\beta + \text{sil } 2\beta + \gamma - 1 + \frac{\sin 2\beta}{2\beta}\right);$$

hence

$$\text{I}+\text{II}+\text{III} = \frac{2i_0^2}{C}\left\{\log_e 2\beta + \text{sil } 2\beta + \gamma - \sin^2\beta\right\};$$

$$\therefore\quad R_l = \frac{1}{C}\left\{\log_e 2\beta + \text{sil } 2\beta + \gamma - \sin^2\beta\right\}.$$

The interaction resistance R_m defined by

$$R_m\left(\frac{i_0}{\sqrt{2}}\right)^2 = -\text{III, is}$$

$$R_m = 120\left(\cos^2\beta - \frac{\sin 2\beta}{2\beta}\right) \text{ ohms.}$$

On the loop current basis

$$r_m = \frac{1}{4}R_m.$$

When the far end of the wire is not open ended but terminated into an impedance with reflection coefficient $\rho e^{i\Psi}$, the phase angle between $H_{\Theta\infty}$ and $H_{\Theta\infty}'$ is not $(\pi-\beta)$ but $(-\beta+\Psi)$. In this case the field

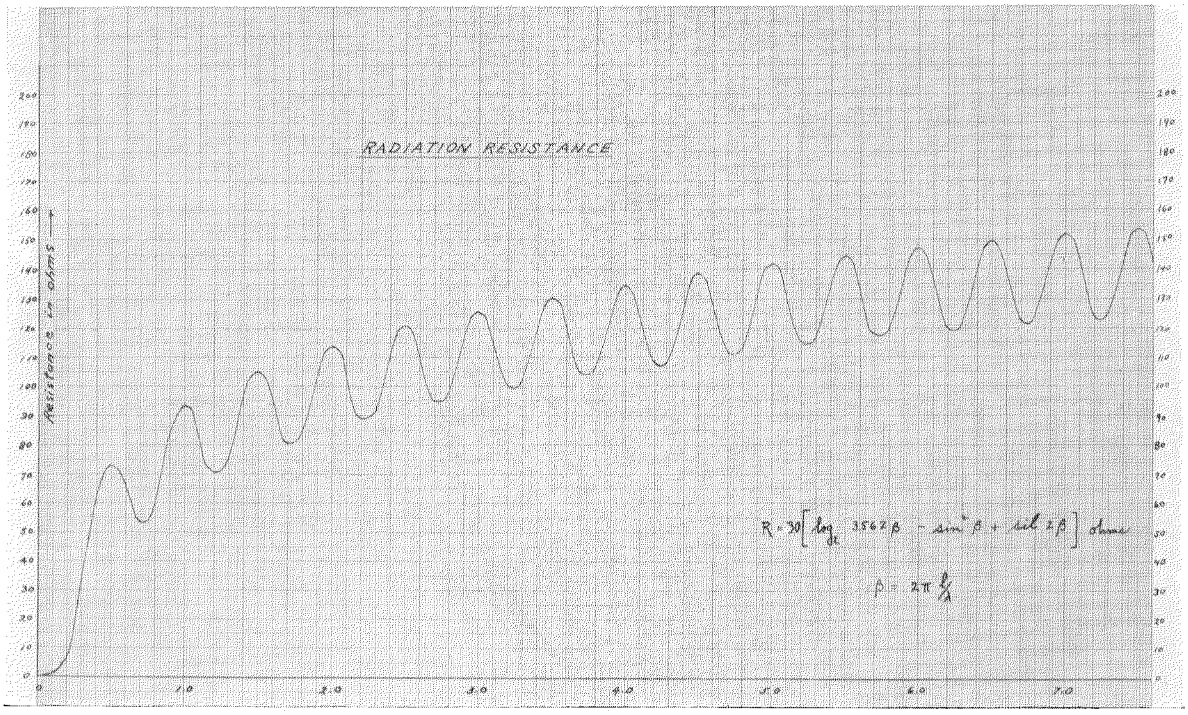
$$|h_{\Theta\infty}| = \sqrt{|H_{\Theta\infty}|^2 + |H_{\Theta\infty}'|^2 + 2H_{\Theta\infty}H_{\Theta\infty}'\cos(\beta-\Psi)}$$

and the mutual interaction resistance (on the $i_0/\sqrt{2}$ basis) is

$$R_m = -120\left[\cos\beta - \frac{\sin\beta}{\beta}\right]\cos(\beta-\Psi) \text{ ohms.}$$

The total radiation resistance on the $(i_0/\sqrt{2})$ basis is

$$R_T = R + \rho^2 R + \rho R_m,$$



Length of Antenna —— l/λ ⟶

Fig. 10

where R is the radiation resistance of a terminated wire of the same length.

So far, only single wires have been considered. Let us now illustrate by a simple example some of the phenomena which may be expected when more than one terminated wire is employed. In Fig. 11 there are shown two colinear wires AB and BC connected through a phase delay device B. Assume that the system is fed at A and terminated into the surge impedance at C, also that the phase delay device is such that there is no reflection of waves at B.

Let the current along AB be

$$i_1 = i_0 \sin \omega\left(t - \frac{Z}{C}\right).$$

and the current along BC be

$$i_2 = i_0 \sin \omega\left(t - \frac{Z}{C} + \sigma\right).$$

The delay at B is then $-\sigma\omega$ radians. The total power radiated by the whole system consists of four parts:

- the power dissipated by i_1 flowing against its own field E_1;
- the power dissipated by i_2 flowing against its own field E_2;
- the power dissipated by i_1 flowing against E_2;
- the power dissipated by i_2 flowing against E_1.

The first two terms have already been discussed in some detail so that here only the third and the fourth terms need be considered. The average work done per unit time by E_1 on i_2 in element dZ is given by

$$-E_1' i_2 dZ = -\frac{1}{2}\left\{\frac{2i_0}{C}\frac{\cos\omega\sigma}{Z} + \frac{2i_0}{C}\frac{\cos\omega\sigma}{Z-l} + \frac{i_0}{\omega}\frac{\sin\omega\sigma}{Z^2} - \frac{i_0}{\omega}\frac{\sin\sigma\omega}{(Z-l)^2}\right\}dZ;$$

similarly, the average work done per unit time by E_2 on i_1 in element dZ is

$$-E_2' i_1 dZ = -\frac{1}{2}\left\{\frac{i_0}{\omega}\frac{\sin\omega\left[\frac{2(Z-l)}{C}+\sigma\right]}{(Z-l)^2} - \frac{i_0}{\omega}\frac{\sin\omega\left[\frac{2(Z-2l)}{C}+\sigma\right]}{(Z-2l)^2}\right\}.$$

E_1' and E_2' are, of course, the in-phase components of E_1 and E_2. The total power dissipated by interaction is

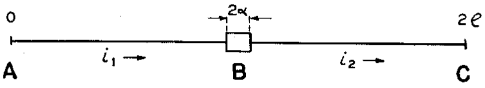


Fig. 11

$$P_i = -\int_{l+\alpha}^{2l} E_1' i_2 dZ - \int_0^{l-\alpha} E_2' i_1 dZ$$

and the total mutual interaction resistance on the $i_0/\sqrt{2}$ basis is then

$$R_m = \frac{C}{i_0^2}60P_i \text{ ohms.}$$

By carrying out the indicated integrations and then letting $\alpha \to 0$,

$$\begin{aligned} R_m = 60\cos\omega\sigma\Bigg\{&\log_e 2 - \frac{R_0}{60} \\ &-\left[\frac{\sin 2\beta}{2\beta} - \frac{\sin 4\beta}{4\beta} + \text{sil } 2\beta - \text{sil } 4\beta\right]\Bigg\} \\ +60\sin\omega\sigma\Bigg\{&-\frac{1}{4\beta} - \frac{1-\cos\beta}{2\beta} + \int_0^{2\beta}\frac{\sin\phi}{\phi}d\phi \\ &+\left[\frac{\cos 2\beta}{2\beta} - \frac{\cos 4\beta}{4\beta} - \int_{2\beta}^{4\beta}\frac{\sin\phi}{\phi}d\phi\right]\Bigg\}. \end{aligned}$$

When $l > \lambda$,

$$R_m \approx 60\cos\omega\sigma\left[\log_e 2 - \frac{R_0}{60}\right] + 60\sin\omega\sigma\left[\frac{\pi}{2} - \frac{3}{4\beta}\right] \text{ ohms,}$$

where R_0 is the radiation resistance of a terminated wire of length l and

$$\beta = 2\pi\frac{l}{\lambda}.$$

EXAMPLE

Suppose that $l = 2\lambda$, then $R_0 = 168$ ohms and

$$\begin{aligned} R_m &= -127\cos(\omega\sigma) + 90.5\sin(\omega\sigma) \\ &= 156\cos[(\omega\sigma) - 144.5°]. \end{aligned}$$

The total radiation resistance of the system is thus

$$R_t = 2R_0 + R_m = 336 + 156\cos(\omega\sigma - 144.5°) \text{ ohms.}$$

The maximum radiation resistance of 492 ohms is obtained with phase delay of 215.5° and minimum radiation resistance of 180 ohms, with phase delay of 35.5°.

The radiation resistance of a single wire 4λ long is, of course,

$$R_4 = 336 + 156 \cos (144.5°) = 209 \text{ ohms.}$$

It may be of interest to note that the major lobes radiated by the individual wires add in phase and result in maximum directional radiation when the delay at B is 237°. This value of delay corresponds to the total radiation resistance of 479 ohms. Thus a radiating system made up of terminated wires may have maximum directivity at the very time when its total radiation resistance is nearly maximum. This result is in direct contrast with the usual conclusion that the directivity varies inversely as the total radiation resistance.

Before leaving this subject, it must be pointed out that all of the above calculations of radiation resistance are subject to correction for attenuation due to radiation. As long as the calculated values of radiation resistance on the $i_0/\sqrt{2}$ basis are small in comparison with the surge impedances of the radiating wires, this correction is quite small. When, however, the values of radiation resistance differ only slightly from the value of surge impedance, this correction may be fairly large. Indeed, the radiation resistance of a very long terminated wire should asymptotically approach some value close to the surge impedance of the wire. For this reason equation (26A) cannot be regarded as even approximately accurate when the value of R calculated from it is nearly equal to the surge impedance of the wire.

II. The First Method

In accordance with the first or Vector-Scalar Potential Method, the components of the electromagnetic field at a point P in space are calculated from the following equations:

$$H = \text{curl } A, \tag{30}$$

$$E = -\frac{1}{C}\frac{\delta A}{\delta t} - \text{grad } \phi, \tag{31}$$

$$\bar{A} = \int \frac{[i]}{r} dv, \tag{32}$$

$$\phi = \int \frac{[\sigma]}{r} dv. \tag{33}$$

In these equations H is the magnetic field, E the electric field, i the conduction current along the radiating conductor, σ the charge density in the conductor, $\bar{A}$ an auxiliary vector usually referred to as vector potential, and ϕ is an auxiliary scalar (scalar potential). r is the distance between point $P(X, Y, Z)$ in space and a point (X_0, Y_0, Z_0) on the conductor. dv is an element of volume. Symbols [ ] are used to indicate that, in the function within the brackets, time t has been replaced by $(t - r/C)$. The integrations extend over the whole volume of the conductor. When the conductor extends in more than one dimension, current i is a vector which has two or more components. Accordingly, $\bar{A}$ is also a vector.

The above fundamental equations may be derived from Maxwell's equations and some additional assumptions in the following manner: Consider Maxwell's equations

$$\text{curl } H - \frac{1}{C}\dot{E} = \frac{4\pi i}{C}, \quad \text{(a)} \qquad \text{curl } E + \frac{1}{C}\dot{H} = 0, \quad \text{(c)}$$

$$\text{div } E = 4\pi\sigma, \quad \text{(b)} \qquad \text{div } H = 0. \quad \text{(d)}$$

From (a) and (b) it follows that

$$\text{div } i + \dot{\sigma} = 0. \quad \text{(e)}$$

In these equations dots placed above various quantities indicate partial differentiations with respect to time. If we let

$$H = \text{curl } A \tag{34}$$

we have, in view of (c), curl $\left[E + \frac{\dot{A}}{C}\right] = 0$. The fact that the curl of vector $\left[E + \frac{1}{C}\dot{A}\right]$ is zero, makes it possible to put

$$E + \frac{1}{C}\dot{A} = -\text{grad } \phi$$

without limiting $\left[E + \frac{1}{C}\dot{A}\right]$ in any way whatsoever. ϕ, of course, is as yet an unknown scalar. We are now in a position to express both E and H in terms of the new quantities A and ϕ. By introducing these quantities into (a) and (b) we get

$$\text{curl curl } A + \frac{1}{C^2}\ddot{A} + \frac{1}{C}\text{grad } \dot{\phi} = 4\pi\frac{i}{C}, \tag{35}$$

$$-\text{div } \dot{A} - \nabla^2\phi = 4\pi\sigma. \tag{36}$$

Let us now *assume* that A and ϕ are such that

$$\operatorname{div} A+\frac{1}{C}\dot{\phi}=0; \tag{37}$$

then (35) and (36) become

$$\nabla^2 A-\frac{\delta^2 A}{\delta t^2}\frac{1}{C^2}=-\frac{4\pi}{C}i, \tag{38}$$

$$\nabla^2 \phi-\frac{\delta^2 \phi}{\delta t^2}\frac{1}{C^2}=-4\pi\sigma. \tag{39}$$

These equations, as is well known, have the following solutions:

$$A=\frac{1}{C}\int\frac{[i]}{r}dv, \tag{40}$$

$$\phi=\int\frac{[\sigma]}{r}dv, \tag{41}$$

in which the indicated integrations extend over that portion of space where i and σ are different from zero.

If we retrace the steps we have taken to derive (40) and (41) in the reverse direction, starting with (40) and (41), we will have the proof of the following theorem:

If

$$A=\frac{1}{C}\int\frac{[i]}{r}dv$$

and

$$\phi=\int\frac{[\sigma]}{r}dv,$$

and if A and ϕ are such that

$$\operatorname{div} A+\frac{1}{C}\dot{\phi}=0,$$

then

$$H=\operatorname{curl} A,$$

$$E=-\frac{\delta A}{\delta t}-\operatorname{grad}\phi$$

are solutions of Maxwell's equations and consequently the correct solutions of a given problem.

Let us now ask the following questions: Suppose we are given a certain distribution of i and σ, what guaranty is there that A and ϕ calculated from this distribution are such that

$$\operatorname{div} A+\frac{1}{C}\dot{\phi}=0?$$

Or, in general, what distributions of i and σ, if any, will give us A and ϕ which do satisfy this condition?

In order to answer these questions, we must express condition (37) in terms of i and σ themselves. By replacing A and ϕ in (37) by their expressions in terms of i and σ, we obtain

$$\operatorname{div}\frac{1}{C}\int\frac{[i]}{r}dv+\frac{\delta}{\delta t}\int\frac{[\sigma]}{Cr}dv=0.$$

Now since the integrations are to be performed with respect to coordinates X_0, Y_0, Z_0 of points on the conductor while the divergence is taken with respect to entirely independent coordinates X, Y, Z of a point P in space, we may reverse the order of these operations. Similarly the differentiation with respect to t may also be carried under the integral sign. Thus we get

$$\int\left[\operatorname{div}_{XYZ}\frac{[i]}{r}+\frac{[\dot{\sigma}]}{r}\right]dv=0. \tag{42}$$

At this point the following observations are pertinent:

We are dealing with two entirely independent sets of coordinates: coordinates of a point P in space X, Y, Z and coordinates of a point on the conductor X_0, Y_0, Z_0. Current i is a function of $X_0Y_0Z_0$ and t;

$$i=i(t, X_0, Y_0, Z_0).$$

Distance r is a function of both sets of coordinates,

$$r^2=(X-X_0)^2+(Y-Y_0)^2+(Z-Z_0)^2;$$

$[i]$ is also a function of both sets of coordinates:

$$[i]=i\left[\left(t-\frac{r}{C}\right), X_0, Y_0, Z_0\right].$$

Divergence which occurs in (42) or in (37) is taken with respect to coordinates X, Y, Z of a point in space and will be designated by div_{XYZ}, in order to distinguish it from a divergence taken with respect to coordinates $X_0Y_0Z_0$, which will be denoted by $\operatorname{div}_{X_0Y_0Z_0}$. Now

$$\begin{aligned}\operatorname{div}_{XYZ}[i]&=\operatorname{div}_{XYZ}i\left[\left(t-\frac{r}{C}\right), X_0, Y_0, Z_0\right]\\&=\frac{\delta[i]}{\delta X}+\frac{\delta[i]}{\delta Y}+\frac{\delta[i]}{\delta Z}\\&=\frac{\delta[i]}{\delta t}\left(-\frac{1}{C}\frac{\delta r}{\delta X}\right)+\frac{\delta[i]}{\delta t}\left(-\frac{1}{C}\frac{\delta r}{\delta Y}\right)\\&\qquad+\frac{\delta[i]}{\delta t}\left(-\frac{1}{C}\frac{\delta r}{\delta Z}\right)\\&=\frac{\delta[i]}{\delta t}\left(\frac{1}{C}\frac{\delta r}{\delta X_0}+\frac{1}{C}\frac{\delta r}{\delta Y_0}+\frac{1}{C}\frac{\delta r}{\delta Z_0}\right),\end{aligned} \tag{42A}$$

since

$$\frac{\delta r}{\delta X}=-\frac{\delta r}{\delta X_0},\quad \frac{\delta r}{\delta Y}=-\frac{\delta r}{\delta Y_0},\quad \frac{\delta r}{\delta Z}=-\frac{\delta r}{\delta Z_0}.$$

On the other hand,

$$\text{div}_{X_0Y_0Z_0}[i]=-\frac{\delta[i]}{\delta t}\left(\frac{1}{C}\frac{\delta r}{\delta X_0}+\frac{1}{C}\frac{\delta r}{\delta Y_0}+\frac{1}{C}\frac{\delta r}{\delta Z_0}\right)+[\text{div}_{X_0Y_0Z_0}i], \quad (43)$$

where by $[\text{div}_{X_0Y_0Z_0}i]$ is meant $\text{div}_{X_0Y_0Z_0}i$ in which t has been replaced by $\left(t-\frac{r}{C}\right)$ *after* the differentiations had been performed. From (42A) and (43) it follows that

$$\text{div}_{XYZ}[i]=-\text{div}_{X_0Y_0Z_0}[i]+[\text{div}_{X_0Y_0Z_0}i]. \quad (44)$$

The continuity equation (*e*) which, of course, holds along the conductor, requires that

$$\text{div}_{X_0Y_0Z_0}i+\dot{\sigma}=0$$

for any and all values of t and, in particular, for $t'=\left(t-\frac{r}{C}\right)$; consequently also

$$[\text{div}_{X_0Y_0Z_0}i]+[\dot{\sigma}]=0. \quad (45)$$

If B is any vector,

$$\text{div}\left(\bar{B}\frac{1}{r}\right)=\frac{\text{div}\,\bar{B}}{r}+\bar{B}\cdot\text{grad}\,\frac{1}{r},$$

in which the divergences are taken with respect to any system of coordinates. Therefore,

$$\text{div}_{XYZ}\left\{[i]\frac{1}{r}\right\}=\frac{\text{div}_{XYZ}[i]}{r}+[i]\cdot\text{grad}_{XYZ}\,\frac{1}{r},$$

$$\text{div}_{X_0Y_0Z_0}\left\{[i]\frac{1}{r}\right\}=\frac{\text{div}_{X_0Y_0Z_0}[i]}{r}+[i]\cdot\text{grad}_{X_0Y_0Z_0}\,\frac{1}{r}.$$

Now since

$$\text{grad}_{XYZ}\frac{1}{r}=-\text{grad}_{X_0Y_0Z_0}\frac{1}{r},$$

$$\text{div}_{XYZ}\frac{[i]}{r}+\text{div}_{X_0Y_0Z_0}\frac{[i]}{r}=\frac{\text{div}_{XYZ}[i]+\text{div}_{X_0Y_0Z_0}[i]}{r}$$

or, in view of (44),

$$\text{div}_{XYZ}\frac{[i]}{r}=\frac{[\text{div}_{X_0Y_0Z_0}i]}{r}-\text{div}_{X_0Y_0Z_0}\frac{[i]}{r}. \quad (46)$$

With the help of the above auxiliary equations, we may now simplify equation (42). In fact, if in (42) we replace $\text{div}_{XYZ}\frac{[i]}{r}$ by its value as given by (46), we obtain

$$\int\left\{\frac{[\text{div}_{X_0Y_0Z_0}i]+\dot{\sigma}}{r}-\text{div}_{X_0Y_0Z_0}\frac{[i]}{r}\right\}dv=0.$$

In view of (45) this reduces to

$$\int\text{div}_{X_0Y_0Z_0}\frac{[i]}{r}dv=0. \quad (47)$$

In accordance with the well known theorem due to Gauss the volume integral of divergence of a vector is equal to the surface integral of the normal component of the same vector; hence,

$$\int\text{div}_{X_0Y_0Z_0}\frac{[i]}{r}dv=\int_S\left[\frac{[i]}{r}\right]_n dS$$
$$=\int_S\frac{[i]_n}{r}dS=0 \quad (48)$$

and this must hold for any and all locations of point P in space.

When the conductor is entirely disconnected from all other conductors, the component of current normal to the boundary of the conductor is certainly equal to zero at all points on the surface and

$$\int_S\frac{[i]_n}{r}dS=0.$$

But when a conductor is fed with power, the situation is quite different.

Assume, for example, that the conductor receives current through two small areas S_1 and S_2. Then $[i]_n$ is zero except at S_1 and S_2; consequently,

$$\int_S\frac{[i]_n}{r}dS=\frac{[i_1]_n}{r_1}S_1+\frac{[i_2]_n}{r_2}S_2.$$

In this equation r_1 and r_2 are distances from S_1 and S_2 to a point P in space. Obviously in this case $\int_S\frac{[i]_n}{r}dS$ cannot be equal to zero for all possible locations of P unless both $[i_1]_n$ and $[i_2]_n$ are equal to zero.

Thus we have arrived at the following conclusion:

(1) When a conductor is disconnected from all others so that no current either enters or leaves it

$$\int_S\frac{[i]_n}{r}dS=0$$

and hence the condition

$$\operatorname{div} A+\frac{1}{C}\dot{\phi}=0$$

fulfilled.

(2) When a conductor is fed, this condition is in general not satisfied.

From these considerations, it follows that when the vector-scalar potential method is applied to wires which are an integral number of half wavelengths long and which are considered to be free of feeders, the results obtained will be correct. But when this method is applied to such systems as, for example, a terminated wire in which current must enter and leave, the results in general will be wrong.

As an illustration of the erroneous result which may be obtained by this method when

$$\operatorname{div} A+\frac{1}{C}\dot{\phi}\neq 0,$$

the following calculation of the electric field due to a terminated wire of length l is presented. The current is assumed to be

$$i=i_0 \sin \omega\left(t-\frac{Z_0}{C}\right);$$

hence

$$\sigma=\frac{i_0}{C}\sin \omega\left(t-\frac{Z_0}{C}\right)$$

and consequently,

$$A=\frac{1}{C}\int_0^l \frac{i_0 \sin \omega\left(t-\frac{r}{C}-\frac{Z_0}{C}\right)}{r}\,dZ_0,$$

$$\phi=\frac{1}{C}\int_0^l \frac{i_0 \sin \omega\left(t-\frac{r}{C}-\frac{Z_0}{C}\right)}{r}\,dZ_0,$$

$$E_Z=-\frac{1}{C}\frac{\delta A}{\delta t}-\frac{\delta \phi}{\delta Z}.$$

Since

$$\frac{\delta}{\delta Z}\left[\frac{\sin \omega\left(t-\frac{r}{C}-\frac{Z_0}{C}\right)}{r}\right]=\sin \omega\left(t-\frac{r}{C}-\frac{Z_0}{C}\right)\frac{\delta}{\delta Z}\left(\frac{1}{r}\right)+\frac{1}{r}\cos \omega\left(t-\frac{r}{C}-\frac{Z_0}{C}\right)\frac{\delta}{\delta Z}\left(-\frac{r\omega}{C}\right),$$

$$\frac{\delta}{\delta Z_0}\left[\frac{\sin \omega\left(t-\frac{r}{C}-\frac{Z_0}{C}\right)}{r}\right]=\sin \omega\left(t-\frac{r}{C}-\frac{Z_0}{C}\right)\frac{\delta}{\delta Z_0}\left(\frac{1}{r}\right)+\frac{1}{r}\cos \omega\left(t-\frac{r}{C}-\frac{Z_0}{C}\right)\left[\frac{\delta}{\delta Z_0}\left(-\frac{r\omega}{C}\right)-\frac{\omega}{C}\right];$$

and since

$$\frac{\delta}{\delta Z}\left(\frac{1}{r}\right)=-\frac{\delta}{\delta Z_0}\left(\frac{1}{r}\right);\qquad \frac{\delta}{\delta Z}(r)=-\frac{\delta}{\delta Z_0}(r),$$

it follows that

$$\frac{\delta}{\delta Z}\frac{\sin \omega\left(t-\frac{r}{C}-\frac{Z_0}{C}\right)}{r}=-\frac{\delta}{\delta Z_0}\frac{\sin \omega\left(t-\frac{r}{C}-\frac{Z_0}{C}\right)}{r}-\frac{1}{C}\frac{\cos \omega\left(t-\frac{r}{C}-\frac{Z_0}{C}\right)}{r}.$$

Hence

$$E_Z=-\frac{1}{C}\frac{\delta A}{\delta t}+\frac{1}{C}\int_0^l \frac{\delta}{\delta Z_0}\frac{i_0 \sin \omega\left(t-\frac{r}{C}-\frac{Z_0}{C}\right)}{r}\,dZ_0+\frac{\omega}{C^2}\int_0^l \frac{i_0 \cos \omega\left(t-\frac{r}{C}-\frac{Z_0}{C}\right)}{r}\,dZ_0.$$

In this expression, the last term is equal to $\frac{1}{C}\frac{\delta A}{\delta t}$ so that

$$E_Z=\frac{1}{C}\int_0^l \frac{\delta}{\delta Z_0}\frac{i_0 \sin \omega\left(t-\frac{r}{C}-\frac{Z_0}{C}\right)}{r}\,dZ_0=\frac{i_0}{C}\left.\frac{\sin \omega\left(t-\frac{r}{C}-\frac{Z_0}{C}\right)}{r}\right|_0^l=-\frac{i_0 \sin \omega\left(t-\frac{r_1}{C}\right)}{Cr_1}+\frac{i_0 \sin \omega\left(t-\frac{r_2}{C}-\frac{l}{C}\right)}{Cr_2}.$$

This result, while it is offhand apparently reasonable, is of course wrong. This may be seen by comparing it with equation (23).

Summary and Remarks

Two procedures for calculating radiation fields have been discussed in some detail. It was shown that while the first procedure is applicable only to unfed and unterminated radiators, the other is quite free from these limitations. The second was used to derive the expressions for the magnetic and the electric fields produced by traveling waves progressing along a linear conductor of length l. These expressions hold along the conductor, near the conductor, as well as at a large distance from the conductor. The energy radiated by traveling waves which progress along a conductor of length l was calculated and expressed in terms of Radiation Resistance defined in a suitable manner. It was shown that the fraction of energy lost by traveling waves, through radiation, depends on the surge impedance of the radiating conductor. The lower this surge impedance, the greater is the fraction of energy radiated by the traveling waves; hence the rate of attenuation due to radiation is also greater. Therefore, an antenna, employing terminated conductors, is made more efficient by reducing the surge impedance of these conductors. The values of Radiation Resistance calculated in the paper enable one to estimate the radiation attenuation.

By making use of the expressions for the magnetic and electric fields due to traveling waves, the fields produced by open ended conductors were calculated. These calculations were based on the assumption that the amplitude of the reflected wave is equal to the amplitude of the forward wave, in order that the results obtained from the present theory may be more readily compared with the well known results obtained by Max Abraham[4] and Pistolkors[4] for wires an integral number of half wave-lengths long. For the sake of completeness, the fields produced by wires of any length, as well as the radiation resistance of such wires, were calculated on the same assumption. The radiation resistance versus length of wire curve thus obtained (see Fig. 10) was found to be wavy and not smooth. This result is at variance with the accepted radiation resistance curves found in current literature.

A method for calculating the radiation resistance, as well as the field due to wires of any length and terminated into any impedance, is included.

The effect of a phase delay device placed at the center of a wire terminated into its surge impedance was considered in some detail. These calculations show that the radiation efficiency of terminated conductors is increased by the use of phase changers. It can be shown also that the fields, produced at a distant point by wires equipped with phase changers, are greater than those produced by continuous wires of the same length.

No attempt was made in this paper to treat the subject of radiation attenuation in as much detail as it deserves. It should be pointed out, however, that in calculations of radiation fields as well as of radiation from very long radiators or from long radiators equipped with phase changers, the radiation attenuation must be taken into account if erroneous results are to be avoided. When the radiation resistances on the $i_0/\sqrt{2}$ basis are not too large in comparison with the surge impedances, first approximations may be secured by simply calculating the attenuation of the forward waves from the radiation resistance, as explained in the body of the paper, and then assuming that only the current which is left over is reflected from the end of the conductor, so that the total radiation pattern and the second approximation to the radiation resistance of the radiating conductor are calculated on the basis of two waves of unequal amplitudes traveling in opposite directions.

The author, in conclusion, gratefully acknowledges the encouragement, helpful criticisms, and suggestions received in connection with the preparation of this paper from Mr. Haraden Pratt, Vice-President and Chief Engineer, Mackay Radio and Telegraph Company.

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[4] Loc. cit.

The Radio Installation on the Cunard White Star, R.M.S. Queen Mary

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THE R.M.S. Queen Mary of the Cunard White Star, Limited, has been provided with a radio installation entirely in keeping with the high standard of naval architecture and marine engineering represented in the design and construction of this magnificent ship. Undoubtedly, the radio installation is the largest and most complete in the history of marine radio, and has been engineered to meet all commercial telephone and telegraph traffic requirements, in addition to the usual navigational and safety services. Many recent advances in radio technique have been embodied in the design of the radio system, and several features hitherto associated only with land stations have been applied for the first time to a marine radio installation.

In planning the radio telephone installation, every consideration was given to features contributing to the convenience of the passengers or otherwise improving the value of the service. As a result, radio telephone service to or from the Queen Mary is practically on a par with long distance telephone service so familiar to the subscriber on land.

A complete voice-operated switching device, the so-called V.O.D.A.S., which forms part of the ship's radio installation, makes it possible for a passenger to talk on the radio telephone circuits from any one of the 500 telephones of the ship's two-wire telephone exchange, even under the most difficult radio conditions. Passengers' telephones are located in all cabin class staterooms and in booths conveniently located with respect to the various public salons throughout the ship.

A second feature designed to minimize service delays is the duplication of the radio telephone facilities, making it possible to maintain a circuit to Europe simultaneously and independently of a direct circuit to America. Both circuits may also be diverted to Europe or America, thereby providing two independent circuits when required to handle the traffic load.

An innovation introduced to insure complete secrecy of radio telephone conversations against the casual "eavesdropper" is the frequency "wobbler." This equipment is additional to the usual privacy devices and provides the same degree of secrecy as is obtained on high grade overseas radio telephone circuits.

During the maiden voyage, radiotelephone calls were completed from passengers' cabins to points as distant as Cape Town and Johannesburg, South Africa.

Radio Telegraphy

The radio telegraph facilities also have been engineered on an ample scale, permitting the rapid handling of passenger radiograms, navigational services, and extensive press dispatches utilized for the publication of the ship's daily newspaper.

Each of the four normal operating positions is equipped with a typewriter, a telegraph key, and a number of radio receivers, as well as with remote control for starting, stopping, and changing the wavelength of the radio transmitters.

While each position is normally manned by one operator, it is possible for two operators to work at each position for full duplex operation. The

R.M.S. "Queen Mary" Shortly Before Docking at New York.

average operating speed is between 25 and 30 words per minute for manual operation.

For higher speeds and to minimize delays during peak conditions, three auxiliary automatic positions are available. Two positions are equipped with perforators and auto-transmitters, while a third position is fitted with an undulator and typewriter for high speed reception. Telegraph speeds up to 100 words per minute have been obtained under practical conditions.

Broadcasting

The Queen Mary is provided with a complete built-in broadcasting system, rivalling the most modern land broadcasting stations in quality of performance.

The two short wave transmitters, which are also used for telegraphy and commercial telephony, have uniform frequency characteristics up to 8,000 p:s, and the harmonic content is surprisingly low.

Permanent microphone pickup points are available in the principal public salons. The ship's modern soundproof studio possesses excellent acoustical properties and is equipped with a piano.

A special high fidelity radio receiver is available for the reception of important broadcast programs from land stations. These programs can be distributed to any part of the ship through the numerous loudspeakers of the ship's sound rediffusion system.

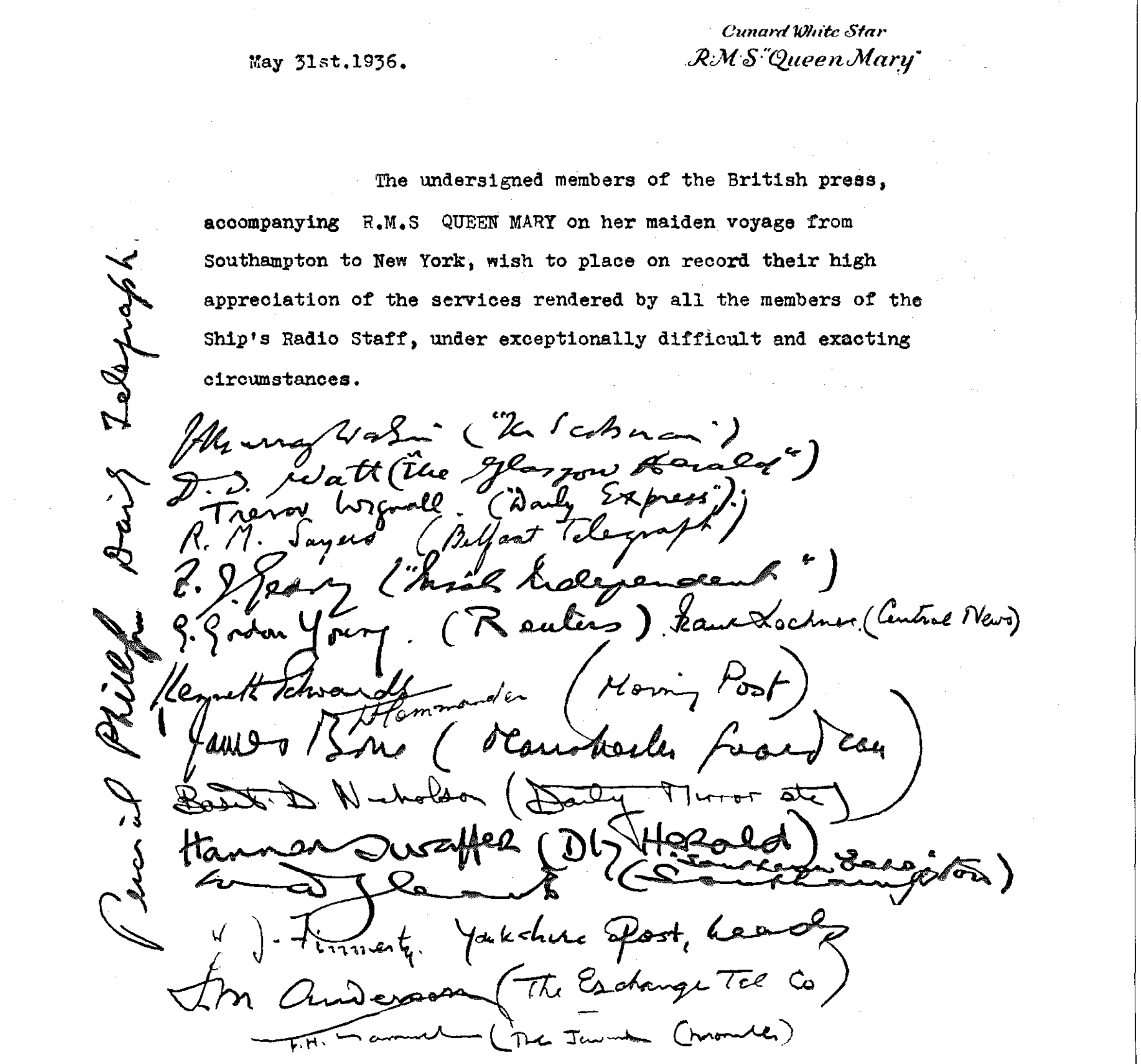
On the maiden voyage, numerous broadcast programs of various durations up to three-quarters of an hour were transmitted successfully to England, France, Denmark, and Holland, and were distributed in America over several nation-wide hookups.

Navigational and Safety Services

One of the principal duties of the radio staff at sea is to keep a permanent watch for distress signals. There are also numerous navigational instructions, weather reports, ice and obstruction warnings, etc., to be received at regular intervals. The Queen Mary, in fact, will at no time be too much occupied to work even the smallest collier or tramp on the 600–800 meter band, in addition to listening for distress signals. Reliable equipment obviously is required for these services.

These requirements are substantially met by one long and one medium wave transmitter of solid construction with approximate ranges of 2,000 and 1,000 miles, respectively. A bank of selective and stable receivers covering the same wavelength ranges ensures uninterrupted reception. These equipments are also utilized for handling commercial radiograms during the intervals when not required for the more important navigational services.

For safety purposes, an independent unit



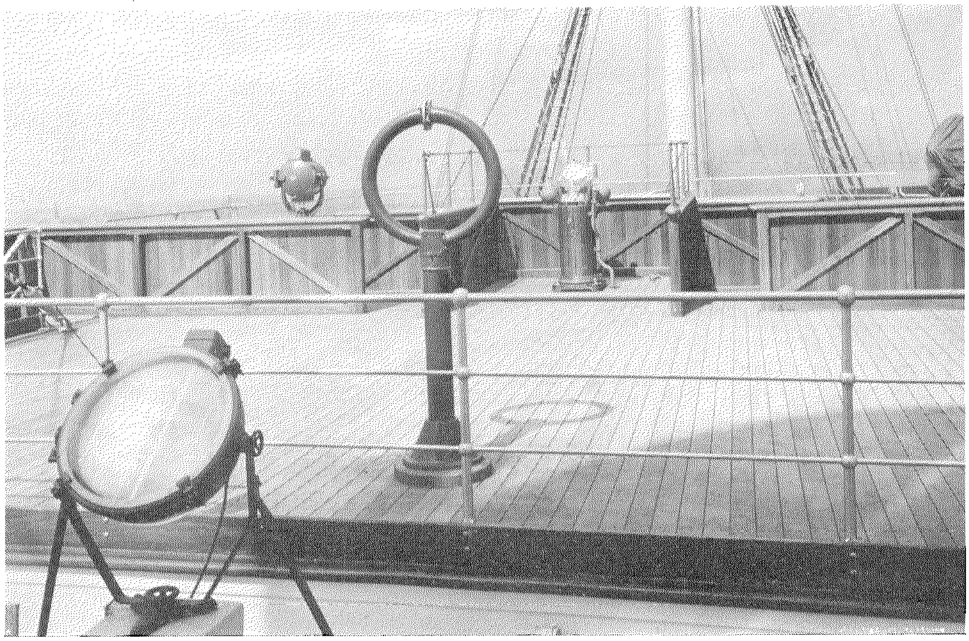
Cunard White Star
R.M.S. "Queen Mary"

May 31st.1936.

The undersigned members of the British press, accompanying R.M.S QUEEN MARY on her maiden voyage from Southampton to New York, wish to place on record their high appreciation of the services rendered by all the members of the Ship's Radio Staff, under exceptionally difficult and exacting circumstances.

J. Murray Watson ("The Scotsman")
D. D. Watt ("The Glasgow Herald")
Trevor Wignall. ("Daily Express")
R. M. Sayers (Belfast Telegraph)
("Irish Independent")
G. Gordon Young. (Reuters) Frank Lochner (Central News)
Kenneth Edwards Commander (Morning Post)
James Bone (Manchester Guardian)
~~Basil~~ D. Nicholson (~~Daily~~ Mirror etc)
Hannen Swaffer (Dly Herald)
(Southampton)
W. J. Finnerty. Yorkshire Post, Leeds
J. M. Anderson (The Exchange Tel Co)
F. H. [illegible] (The Jewish Chronicle)
Percival Phillips Daily Telegraph

Testimonial from Members of the British Press.



Rotating Loop Portion of the I.M.R.C. Radio Direction Finder Installed on the Bridge of the R.M.S. Queen Mary.

consisting of a medium wave transmitter and receiver, operated from a storage battery installation, is always kept in readiness in case of major failures or interruptions to the ship's power supply. The emergency transmitter has an approximate range of 500 miles and is of the type normally installed as the main transmitter in ships of average size. Provision has also been made for keying the main transmitters locally from the transmitting room in the event of failure of the control circuits from the operating room.

Two of the motor lifeboats are fitted with radio installations of standard Board of Trade type. In addition, these lifeboats have small radio telephone sets similar to those usually supplied to coasters and trawlers and are so simple to operate that communication can be maintained by any member of the crew in the absence of a skilled radio operator. These are the first ship's boats ever equipped with radio telephony in addition to the usual radio telegraph installation required by the Board of Trade.

The I.M.R.C. Radio Direction Finder is located in a special compartment on the bridge adjacent to the Sperry Gyro Master Compass compartment and near the ship's standard compass. One of the several "repeater" compasses controlled by the Gyro Master Compass is associated with the scale of the direction finder in a manner such that it is possible to obtain the compass bearing of a radio station without reference to a simultaneous reading of the standard compass, as is usually required. The range of the direction finder is 300 to 400 miles. On the return voyage a considerable amount of fog was experienced east of the Bishops, and the direction finder was in constant use as a check upon the position of the ship by dead reckoning. The results obtained proved to be extremely satisfactory, and as a consequence Cherbourg Harbor was made without difficulty and with complete confidence.

Automatic Wave-Change Feature

A large modern liner requires many frequencies or wavelengths—the Queen Mary uses thirty-two different frequencies—for the successful operation of its radio services. Moreover, these frequencies must be shifted frequently during the day in order to meet varying conditions depending largely on time and distance. In the past, the various coils and condensers associated with the radio transmitters were changed manually and the time required for a single wavelength change varied between 5 and 15 minutes. It was usually necessary to keep a permanent watch at the transmitters and close cooperation was essential between the radio operator and transmitter attendant. The alternative solution on small installations was for the operator to leave the circuit while making the necessary changes in the transmitter. In any case, a considerable percentage of the total time was lost and the service was subject to fairly long delays.

The problem was solved on the Queen Mary by means of the simple automatic dial familiar to telephone subscribers and associated with relays similar to those found in an automatic telephone exchange. The ten numbers on the dial correspond to ten different frequencies, and the time required for a complete wavelength change is from 3 to 5 seconds. The four main transmitters on the Queen Mary are on dial control direct from the operating positions located about 400 feet from the transmitting room. In addition to the tremendous saving in time and reduction in service delay, the transmitting room may be left unattended.

Multiplex Operation

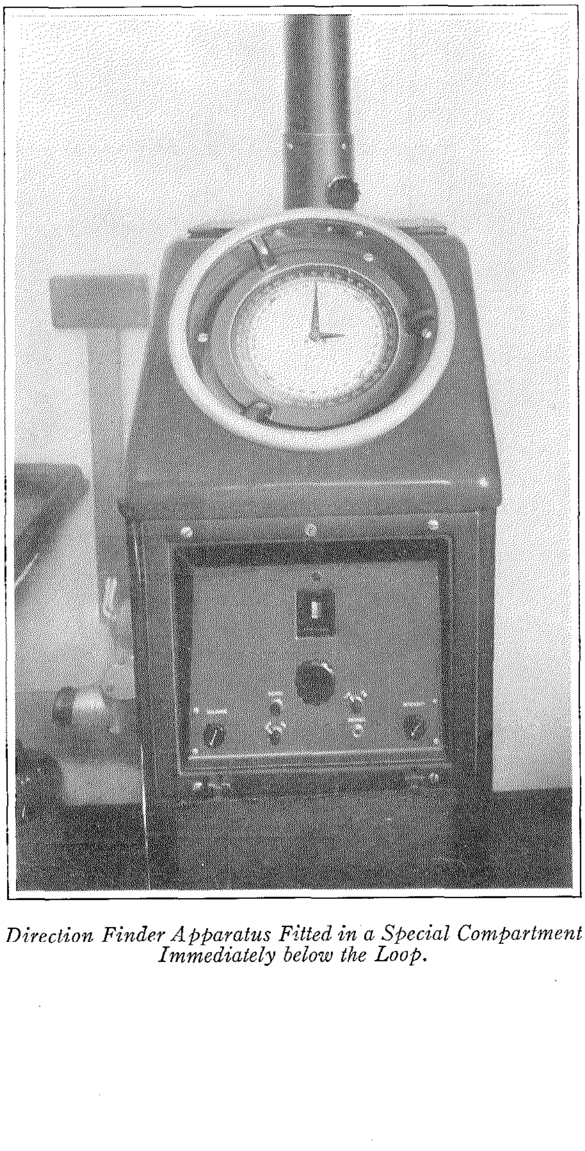
A feature contributing largely to the traffic handling capacity of the Queen Mary's radio installation is multiplex working, one of the most difficult problems that presents itself to the marine engineer. Its solution on land is comparatively simple since the transmitting and receiving aerials are usually separated by a considerable distance. On a ship, however, this separation is reduced to a few yards.

The problem has been completely solved on the Queen Mary by special attention to antenna design, lead-in arrangements, and selective receivers. It is possible to operate duplex telegraph circuits, two-way telephone circuits, and receive broadcast programs while all four transmitters are in operation on full power and on any combination of the thirty-two operating frequencies. On one occasion during the maiden voyage, the traffic volume was so heavy that three outgoing and five incoming telegraph channels were being operated simultaneously while, at the same time, a radio telephone call was in progress.

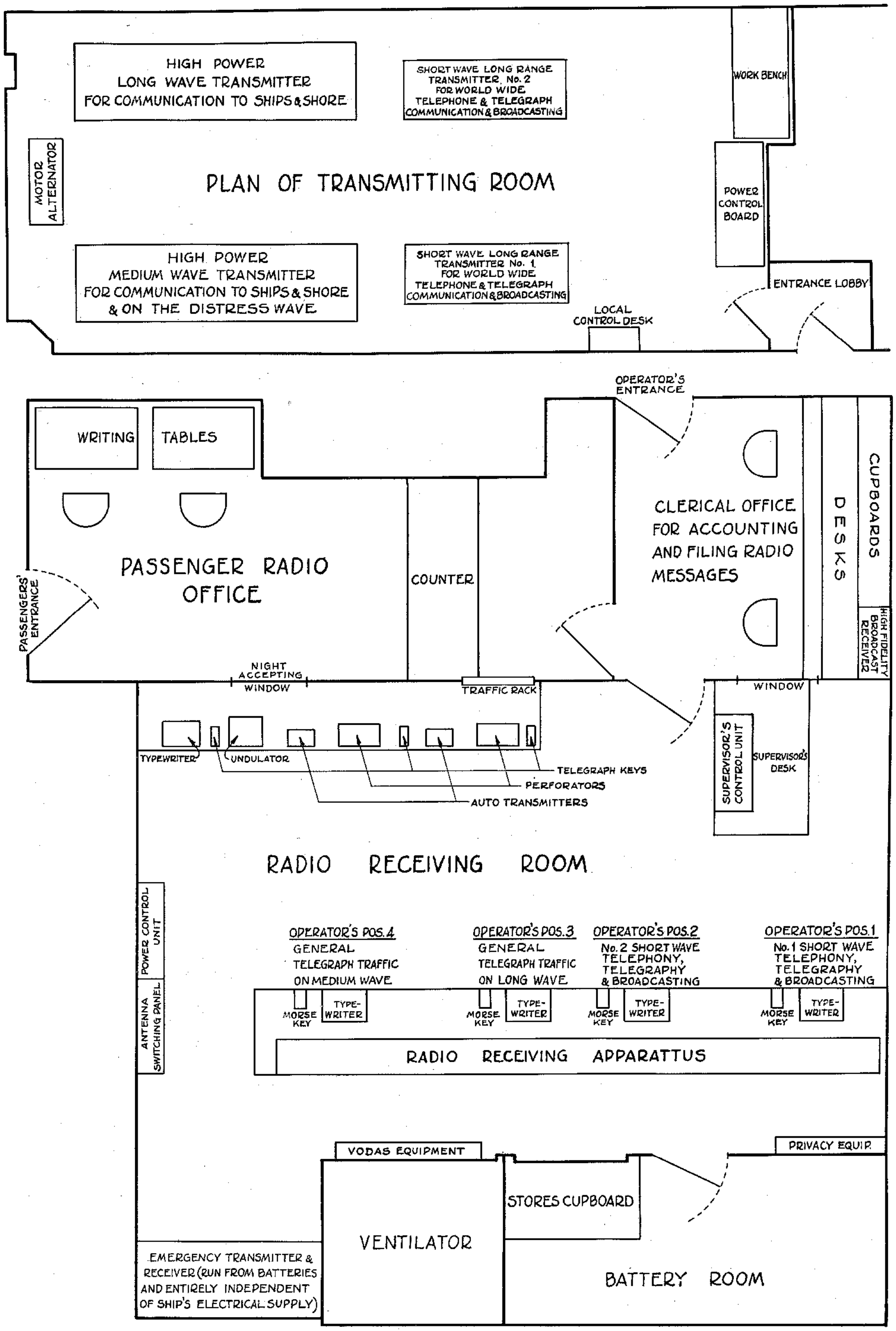
Traffic Handling Capacity

Some idea of the traffic handling capacity of the installation may be gained from the following figures of traffic completed on the maiden westbound voyage. These figures constitute a record by a very wide margin in each of the categories listed and were made possible by two features—automatic wave change and multiplex operation:

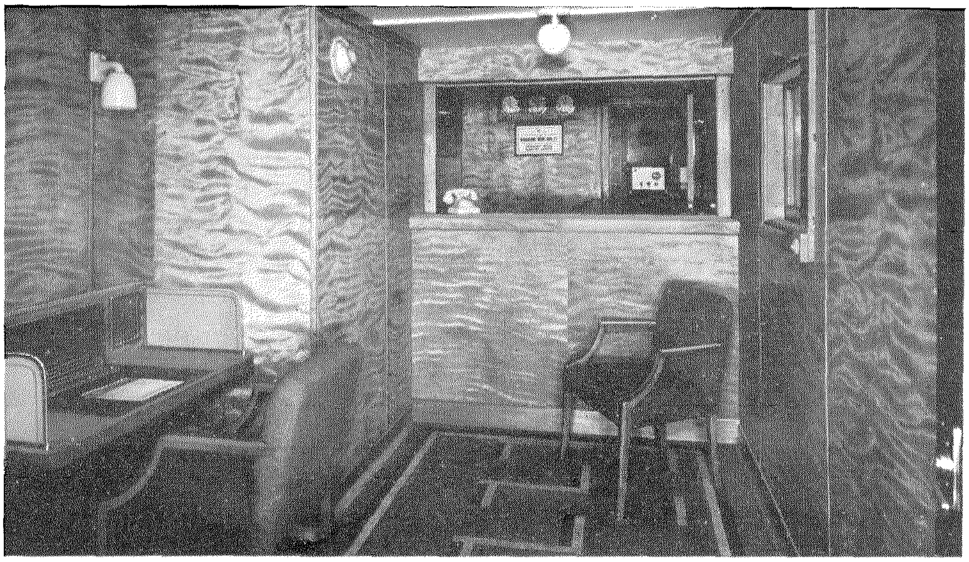
1,808 radiograms transmitted, totalling 95,744 words;



Direction Finder Apparatus Fitted in a Special Compartment Immediately below the Loop.


HIGH POWER LONG WAVE TRANSMITTER FOR COMMUNICATION TO SHIPS & SHORE
SHORT WAVE LONG RANGE TRANSMITTER No. 2 FOR WORLD WIDE TELEPHONE & TELEGRAPH COMMUNICATION & BROADCASTING
WORK BENCH
MOTOR ALTERNATOR
PLAN OF TRANSMITTING ROOM
POWER CONTROL BOARD
HIGH POWER MEDIUM WAVE TRANSMITTER FOR COMMUNICATION TO SHIPS & SHORE & ON THE DISTRESS WAVE
SHORT WAVE LONG RANGE TRANSMITTER No. 1 FOR WORLD WIDE TELEPHONE & TELEGRAPH COMMUNICATION & BROADCASTING
LOCAL CONTROL DESK
ENTRANCE LOBBY
OPERATOR'S ENTRANCE
WRITING TABLES
PASSENGER RADIO OFFICE
PASSENGERS' ENTRANCE
COUNTER
CLERICAL OFFICE FOR ACCOUNTING AND FILING RADIO MESSAGES
DESKS
CUPBOARDS
HIGH FIDELITY BROADCAST RECEIVER
NIGHT ACCEPTING WINDOW
TRAFFIC RACK
WINDOW
TYPEWRITER
UNDULATOR
TELEGRAPH KEYS
PERFORATORS
AUTO TRANSMITTERS
SUPERVISOR'S CONTROL UNIT
SUPERVISOR'S DESK
RADIO RECEIVING ROOM
POWER CONTROL UNIT
ANTENNA SWITCHING PANEL
OPERATOR'S POS. 4 GENERAL TELEGRAPH TRAFFIC ON MEDIUM WAVE
OPERATOR'S POS. 3 GENERAL TELEGRAPH TRAFFIC ON LONG WAVE
OPERATOR'S POS. 2 No. 2 SHORT WAVE TELEPHONY, TELEGRAPHY & BROADCASTING
OPERATOR'S POS. 1 No. 1 SHORT WAVE TELEPHONY, TELEGRAPHY & BROADCASTING
MORSE KEY
TYPE-WRITER
MORSE KEY
TYPE-WRITER
MORSE KEY
TYPE-WRITER
MORSE KEY
TYPE-WRITER
RADIO RECEIVING APPARATTUS
VODAS EQUIPMENT
PRIVACY EQUIP.
STORES CUPBOARD
VENTILATOR
EMERGENCY TRANSMITTER & RECEIVER (RUN FROM BATTERIES AND ENTIRELY INDEPENDENT OF SHIP'S ELECTRICAL SUPPLY)
BATTERY ROOM

Floor Plan of Radio Rooms on the Queen Mary.



Radio Office on Board the Queen Mary.

1,351 radiograms received, totalling 36,119 words;
149 commercial radio telephone calls, totalling 826 minutes;
40 different broadcast programs transmitted from the ship, totalling 647 minutes.

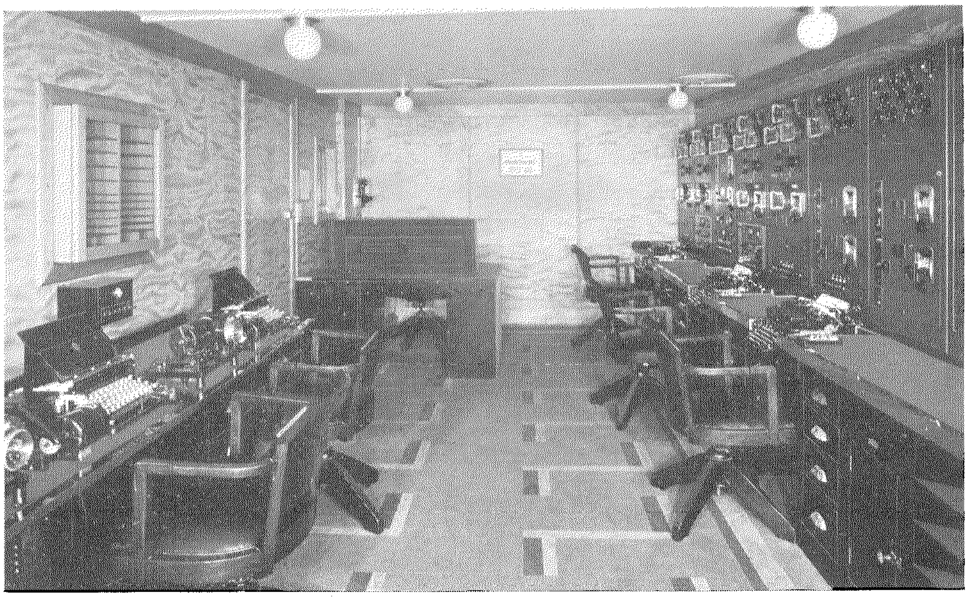
General Description of Radio Installation

The layout and general appearance of the radio rooms are illustrated by the floor plan and photographic views reproduced on these pages.

PASSENGER RADIO OFFICE

The passenger radio office is located on the port side of the sun deck immediately above the main hall, and may be reached by the staircase on either side of the main hall or by the main elevators. Here, radio officers are in constant attendance to care for passengers' requirements. Messages may be received directly across the counter or by telephone from any part of the ship. The principal duties of these officers are to accept radiograms and radio telephone calls, to supervise the delivery of incoming radiograms, to assist in locating a passenger called by a land subscriber, and to supply information regarding rates and addresses. For the latter purposes, tele-

Radio Transmitter Room, Showing the Transmitters Which Are Remotely Controlled from the Radio Operating Room 400 Feet Away.



Radio Operating Room, Showing Some of the Receiving Equipment.

phone directories and information on rates to all parts of the world are available at the counter.

In the passenger office, also, are two comfortable writing desks, suitably equipped with writing materials and message blanks, and a portable typewriter is available for the use of passengers who prefer to type their messages.

Clerical Office

A small clerical office, immediately behind the passenger accepting office, is used for accounting, billing, and filing, and is equipped with the necessary cabinets and desks. Here, incoming radiograms are also prepared for delivery.

Radio Operating Room

The radio operating room is entered through the clerical office. Four operating positions, two for short wave and broadcasting, one for medium wave telegraphy, and one for long wave telegraphy extend the length of the room. The installation comprises eleven receivers, four for short waves, four for medium waves, and three for long waves, in addition to two radio telephone terminal equipments, and the remote control equipment for starting, stopping, changing wavelengths, and adjusting the power output of the radio transmitters.

The auxiliary automatic telegraph equipment is mounted on a separate table opposite the main operating positions. A supervisor's desk and the emergency radio equipment complete this part of the installation.

Radio Transmitter Room

For convenience in antenna lead-in arrangements, the four radio transmitters are located in a separate room about 400 feet aft of the operating room and approximately in the position of the rear mast. The two short wave transmitters deliver about 500 watts to the antenna systems and ten spot wavelengths are available on each transmitter under dial selection. These transmitters are used for telephony, telegraphy, or broadcasting, as required, and insure good communication during practically the entire Atlantic crossing.

The long and the medium wave transmitters deliver approximately 3 kW. to the antenna and are primarily used for telegraphic communication. Seven wavelengths are used for long wave and five wavelengths for medium wave communication. As in the case of the short wave transmitters, automatic dial selection is employed.

The power board, seen at the end of the transmitter room, distributes a-c. power to the various transmitters and all equipment in the operating room.

Power Supply Room

The power supply room, located on a lower deck near the engine rooms, contains a duplicate machine group of 40 kW. each for converting the ship's d-c. supply to 220 volt 3-phase 50 cycle a-c. for the operation of the radio equipment. These machine groups are entirely controlled from the power board in the transmitter room.

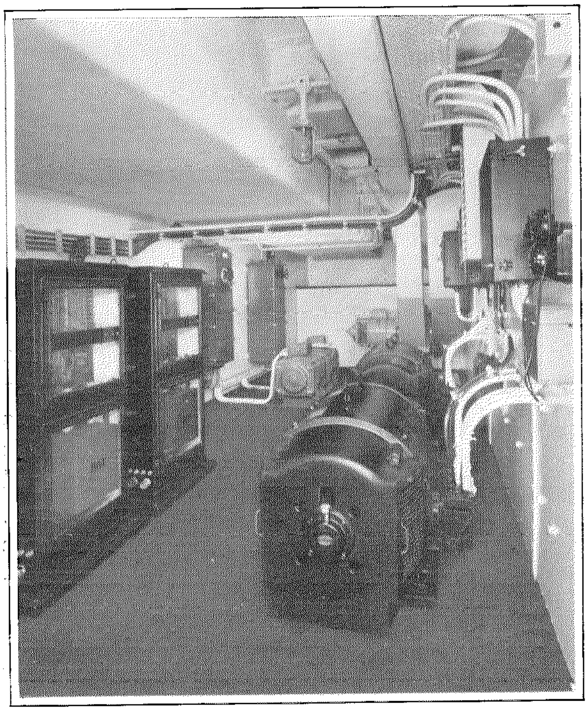
Antenna Systems

The antenna installation comprises four transmitting, five receiving, and one emergency transmitting-receiving aerial. Two features are of special interest:

For short wave transmission, the use of directive aerials is practicable due to the fact that the ship's normal bearing during the major portion of the transatlantic crossing does not vary more than thirty degrees from the bearing of the shore stations.

On the receiving side, coaxial cables similar to those now being installed for broad band transmission are used for transmission lines connecting the aerials to the various receivers. A unique coaxial switching panel permits the selection of any aerial for connection to any receiver.

Various precautions have been taken to insure quiet receiving conditions, such as the provision of filters in all power machinery and equipment throughout the ship. To eliminate the usual troublesome stay noises so familiar on ship installations, all stay wires on the mast and funnels have been securely connected to earth at both ends of the stays. All downhauls on the masts and funnels have been insulated and securely fastened to avoid any possible swinging of these cables against any metallic structures.



Electrical Generating Plant, Supplying Power for the Queen Mary Radio Installation. This Equipment is Duplicated against the Possibility of a Breakdown.

In connection with the successful completion of the Queen Mary radio installation, grateful acknowledgment is made for the assistance and cooperation of the Cunard White Star officials, the Naval Architect, and the Marine Superintendent. The British General Post Office also made special arrangements for exchanging operators on the Queen Mary with those of the Portishead Radio Station, as well as for calibrating the direction finder off the Port Patrick Radio Station.

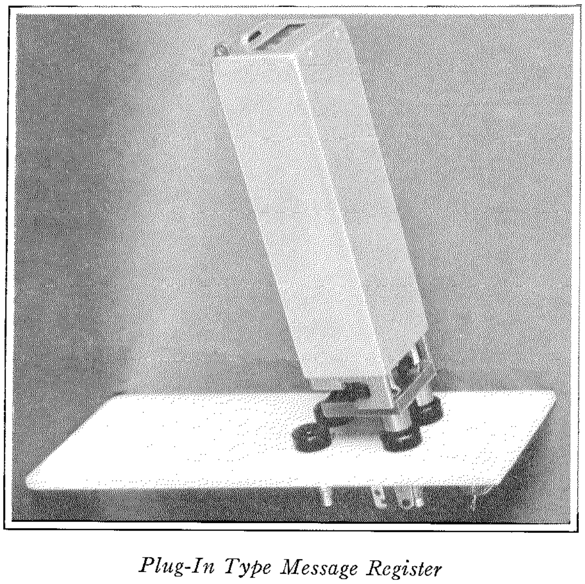
The radio equipment of the R.M.S. Queen Mary was almost entirely manufactured by companies in the International System and was supplied and installed and is operated by the International Marine Radio Company, Limited, under contractual agreement with the Cunard White Star, Limited. The I.M.R.C. has equipped eight of the ten British transatlantic liners so far furnished with facilities for subscribers' radio telephone service.

Recent Telecommunication Developments of Interest

Plug-In Type Message Register. With gradual transfer from flat rate to message rate service, an economical cabling scheme has not been as practicable as in cases where message rate service has been standardized. Since, in general, provision of message registers for all lines simultaneously is not economical, the practice has been to run register cables to spare terminal strips on the M.D.F. to which the lines are jumpered as required. Objections to this procedure are that registers cannot be arranged in the sequence of the subscribers' numbers and, as message rate subscribers increase, it becomes difficult or impossible to provide accommodations for terminal strips or jumpers.

The plug-in type message register has been designed by the Bell Telephone Manufacturing Company, Antwerp, to provide for such cases. It permits a simpler layout and eliminates the costly process of jumpering, cables being run directly from the register rack to the numerical side of the M.D.F. and permanently connected to the existing terminals. When a subscriber is transferred from flat to message rate, all that is necessary is to plug in one of these message registers.

In 7-A.1 Rotary Exchanges, where the message register is connected in parallel with the cut-off relay, and where it is necessary to maintain the combined resistance of message register and cut-off relay at 600 ohms, a plug-in type resistance has been developed for use on lines without message registers. It therefore is possible to change lines from flat rate to message rate without altering the strapping of the cut-off relay.



Plug-In Type Message Register

• • •

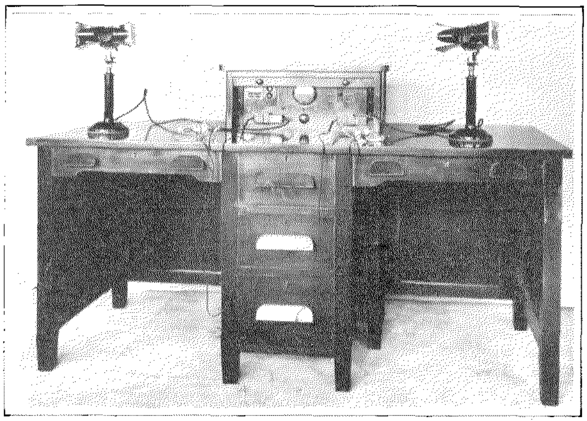
An interesting development of the Bell Telephone Manufacturing Company, Antwerp, Belgium, is the so-called "Speech Translating System."

When meetings are held at which speakers use a language which is not understood by all the delegates present, it has generally been the custom to read a translation of the speech either immediately thereafter or at the end of the conference. Apart from the loss of time involved, this procedure has generally been regarded as unsatisfactory inasmuch as it disturbs the continuity of the meeting and is rather trying to the patience of those who have already heard and understood what has taken place.

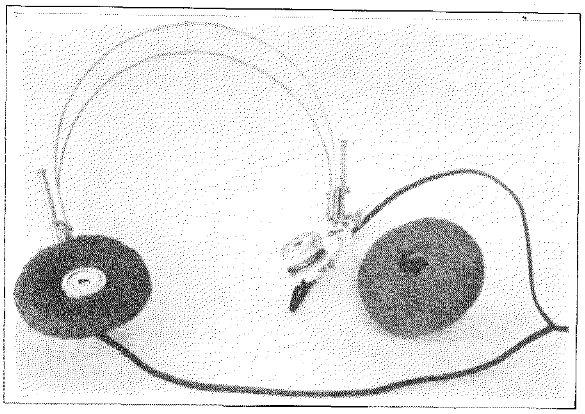
By means of the equipment shown in the accompanying illustration, a translation of the speech can be distributed by means of headphones to any of the delegates present at the time the speech is delivered. Such equipments were recently supplied by the Bell Telephone Manufacturing Company to the "Chambre des Représentants" and to the "Commission Syndicale de Belgique," both of Brussels. So far as is known, they represent the only installations of this character to date, apart from the system in use by the League of Nations at Geneva. Two positions, which can be used either simultaneously to translate into two languages for the benefit of the delegates or as relief desks, are provided at the translator's desk.

The equipment is mains operated. The microphones are of the permanent magnet, moving coil type provided with a special mouthpiece designed to eliminate room noise. The amplifier, which is mounted in the upper part of the desk, provides an amplification of approximately 70 db., the gain-frequency being constant to within 2 db. over the frequency range of 100–6,000 p : s.

A small potentiometer at each listening point provides facilities for volume adjustment. The headphones are of exceptionally light design, weighing only 130 grammes.



Speech Translating System



Lightweight Head Receivers

Telephone and Telegraph Statistics of the World

Compiled by Chief Statistician's Division, American Telephone and Telegraph Company

Telephone Development of the World, by Countries
January 1, 1935

COUNTRIES	NUMBER OF TELEPHONES			Per Cent of Total World	Telephones Per 100 Population
	Government Systems	Private Companies	Total		
NORTH AMERICA:					
United States	—	16,868,955	16,868,955	50.29%	13.36
Canada	190,602	1,003,127	1,193,729	3.56%	11.00
Central America	11,748	13,921	25,669	.08%	0.37
Mexico	1,337	107,315	108,652	.32%	0.62
West Indies:					
Cuba	500	32,494	32,994	.10%	0.79
Puerto Rico	537	11,529	12,066	.04%	0.72
Other W. I. Places	7,594	14,800	22,394	.07%	0.33
Other No. Am. Places	—	11,111	11,111	.03%	3.03
Total	212,318	18,063,252	18,275,570	54.49%	10.47
SOUTH AMERICA:					
Argentina	—	322,873	322,873	.96%	2.69
Bolivia	—	2,218	2,218	.01%	0.07
Brazil	1,924	190,742	192,666	.57%	0.41
Chile	—	50,360	50,360	.15%	1.12
Colombia	7,407	25,377	32,784	.10%	0.34
Ecuador	3,121	3,250	6,371	.02%	0.25
Paraguay	—	2,996	2,996	.01%	0.33
Peru	—	20,985	20,985	.06%	0.32
Uruguay	19,651	12,532	32,183	.09%	1.60
Venezuela	600	18,685	19,285	.06%	0.58
Other So. Am. Places	2,803	—	2,803	.01%	0.52
Total	35,506	650,018	685,524	2.04%	0.75
EUROPE:					
Austria	258,748	—	258,748	.77%	3.82
Belgium**	323,423	—	323,423	.96%	3.91
Bulgaria	20,646	—	20,646	.06%	0.34
Czechoslovakia	150,245	21,401	171,646	.51%	1.13
Denmark#	16,401	361,164	377,565	1.13%	10.31
Finland	2,369	138,698	141,067	.42%	3.75
France	1,399,869	—	1,399,869	4.17%	3.30
Germany#	3,134,103	—	3,134,103	9.34%	4.69
Great Britain and No. Ireland	2,366,311	—	2,366,311	7.06%	5.06
Greece	—	26,712	26,712	.08%	0.40
Hungary	121,067	735	121,802	.36%	1.37
Irish Free State#	34,799	—	34,799	.11%	1.16
Italy	—	516,075	516,075	1.54%	1.19
Jugo-Slavia	47,234	2,612	49,846	.15%	0.34
Latvia#	65,345	—	65,345	.20%	3.35
Netherlands	352,741	—	352,741	1.05%	4.20
Norway*	121,231	78,453	199,684	.60%	6.96
Poland	118,904	92,430	211,334	.63%	0.63
Portugal	10,833	38,633	49,466	.15%	0.70
Roumania	—	56,797	56,797	.17%	0.30
Russia¶	739,381	—	739,381	2.20%	0.43
Spain	—	312,719	312,719	.93%	1.28
Sweden	615,554	1,393	616,947	1.84%	9.90
Switzerland	383,289	—	383,289	1.14%	9.25
Other Places in Europe	85,153	13,290	98,443	.29%	1.29
Total	10,367,646	1,661,112	12,028,758	35.86%	2.13
ASIA:					
British India#	24,328	40,120	64,448	.19%	0.02
China	70,000	94,000	164,000	.49%	0.04
Japan#	1,068,244	—	1,068,244	3.19%	1.56
Other Places in Asia	141,106	66,593	207,699	.62%	0.13
Total	1,303,678	200,713	1,504,391	4.49%	0.14
AFRICA:					
Egypt	49,765	—	49,765	.15%	0.23
Union of South Africa#	140,349	—	140,349	.42%	1.64
Other Places in Africa	97,750	1,970	99,720	.30%	0.09
Total	287,864	1,970	289,834	.87%	0.20
OCEANIA:					
Australia*	501,402	—	501,402	1.49%	7.51
Dutch East Indies	37,407	3,641	41,048	.12%	0.06
Hawaii	—	23,857	23,857	.07%	6.36
New Zealand#	159,170	—	159,170	.48%	10.20
Philippine Islands	6,000	20,358	26,358	.08%	0.19
Other Places in Oceania	3,700	278	3,978	.01%	0.17
Total	707,679	48,134	755,813	2.25%	0.83
TOTAL WORLD	12,914,691	20,625.199	33,539,890§	100.00%	1.58

* June 30, 1934. ** February 28, 1935. # March 31, 1935.

¶ U.S.S.R., including Siberia and Associated Republics.

§ Includes approximately 15,560,000 automatic or "Dial" telephones, of which about 45% are in the United States.

Telephone and Telegraph Wire of the World, by Countries

January 1, 1935

COUNTRIES	Service Operated By (See Note)	MILES OF TELEPHONE WIRE			MILES OF TELEGRAPH WIRE		
		Number of Miles	Per Cent of Total World	Per 100 Population	Number of Miles	Per Cent of Total World	Per 100 Population
NORTH AMERICA:							
United States	P.	86,800,000	55.88%	68.73	2,270,000	32.40%	1.80
Canada	P.G.	5,134,000	3.30%	47.32	367,000	5.24%	3.38
Central America	P.G.	61,000	.04%	0.89	20,000	.28%	0.29
Mexico	P.	557,000	.36%	3.17	90,000	1.28%	0.51
West Indies:							
Cuba	P.	275,000	.18%	6.62	14,000	.20%	0.34
Puerto Rico	P.	33,000	.02%	1.98	2,000	.03%	0.12
Other W. I. Places	P.G.	105,000	.07%	1.54	8,500	.12%	0.12
Other No. Am. Places	P.	19,000	.01%	5.18	11,000	.16%	3.00
Total		92,984,000	59.86%	53.26	2,782,500	39.71%	1.59
SOUTH AMERICA:							
Argentina	P.	1,250,000	.80%	10.42	200,000	2.85%	1.67
Bolivia	P.	5,500	.004%	0.17	5,000	.07%	0.16
Brazil	P.	683,000	.44%	1.46	110,000	1.57%	0.24
Chile	P.	201,000	.13%	4.48	55,000	.79%	1.23
Colombia	P.	130,000	.08%	1.36	20,000	.29%	0.21
Ecuador	P.G.	9,000	.01%	0.36	4,000	.06%	0.16
Paraguay	P.	7,000	.005%	0.78	3,000	.04%	0.33
Peru	P.	60,000	.04%	0.92	12,000	.17%	0.18
Uruguay	P.G.	105,000	.07%	5.21	8,000	.11%	0.40
Venezuela	P.	78,000	.05%	2.34	7,000	.10%	0.21
Other So. Am. Places	G.	6,000	.004%	1.11	500	.01%	0.09
Total		2,534,500	1.63%	2.76	424,500	6.06%	0.46
EUROPE:							
Austria	G.	670,000	.43%	9.89	49,000	.70%	0.72
Belgium**	G.	1,831,000	1.18%	22.12	35,000	.50%	0.42
Bulgaria	G.	67,000	.04%	1.10	7,000	.10%	0.15
Czechoslovakia	P.G.	601,000	.39%	3.95	82,000	1.17%	0.54
Denmark#	P.	1,249,000	.80%	34.10	13,000	.19%	0.35
Finland	P.	350,000	.22%	9.30	18,000	.26%	0.48
France	G.	5,160,000	3.32%	12.16	521,000	7.44%	1.23
Germany#	G.	15,850,000	10.20%	23.73	130,000	1.85%	0.20
Great Britain and No. Ireland#	G.	11,670,000	7.51%	24.98	252,000	3.60%	0.54
Greece	P.	76,000	.05%	1.13	35,000	.50%	0.52
Hungary	G.	400,000	.26%	4.50	45,000	.64%	0.51
Irish Free State#	G.	125,000	.08%	4.17	22,000	.31%	0.73
Italy	P.	1,600,000	1.03%	3.69	266,000	3.80%	0.61
Jugo-Slavia	G.	145,000	.09%	0.99	58,000	.83%	0.39
Latvia#	G.	276,000	.18%	14.15	5,000	.07%	0.26
Netherlands	G.	1,150,000	.74%	13.70	16,000	.23%	0.19
Norway*	P.G.	602,000	.39%	20.98	28,000	.40%	0.98
Poland	P.G.	1,056,000	.68%	3.15	48,000	.68%	0.14
Portugal	P.G.	134,000	.09%	1.89	18,000	.26%	0.26
Roumania	P.	213,000	.14%	1.12	49,000	.70%	0.26
Russia¶	G.	1,300,000	.84%	0.75	600,000	8.56%	0.35
Spain	P.	1,220,000	.79%	4.98	92,000	1.31%	0.38
Sweden	G.	2,275,000	1.46%	36.50	27,000	.38%	0.43
Switzerland	G.	1,362,000	.88%	32.86	15,000	.21%	0.36
Other Places in Europe	P.G.	302,000	.19%	3.96	23,000	.33%	0.30
Total		49,684,000	31.98%	8.81	2,454,000	35.02%	0.44
ASIA:							
British India#	P.G.	424,000	.27%	0.12	427,000	6.09%	0.12
China	P.G.	520,000	.33%	0.04	130,000	1.86%	0.03
Japan#	G.	3,834,000	2.47%	5.58	233,000	3.33%	0.34
Other Places in Asia	P.G.	645,000	.42%	0.40	188,000	2.68%	0.12
Total		5,423,000	3.49%	0.52	978,000	13.96%	0.09
AFRICA:							
Egypt	G.	263,000	.17%	1.23	35,000	.50%	0.16
Union of South Africa#	G.	576,000	.37%	6.73	31,000	.44%	0.36
Other Places in Africa	P.G.	287,000	.19%	0.25	141,000	2.01%	0.12
Total		1,126,000	.73%	0.78	207,000	2.95%	0.14
OCEANIA:							
Australia*	G.	2,581,000	1.66%	38.66	98,000	1.40%	1.47
Dutch East Indies	G.	254,000	.16%	0.38	22,000	.31%	0.03
Hawaii	P.	89,000	.06%	23.73	0	.00%	0.00
New Zealand#	G.	588,000	.38%	37.69	26,000	.37%	1.67
Philippine Islands	P.G.	66,000	.04%	0.48	11,000	.16%	0.08
Other Places in Oceania	P.G.	8,000	.01%	0.35	4,000	.06%	0.17
Total		3,586,000	2.31%	3.94	161,000	2.30%	0.18
TOTAL WORLD		155,337,500	100.00%	7.33	7,007,000	100.00%	0.33

NOTE: Telegraph service is operated by Governments, except in the United States and Canada. In connection with telephone wire, P. indicates that the telephone service is wholly or predominantly operated by private companies. G. wholly or predominantly by the Government, and P.G. by both private companies and the Government. See preceding table.

* June 30, 1934. ** February 28, 1935. # March 31, 1935.

¶ U.S.S.R. including Siberia and Associated Republics.

Telephone Development of Large and Small Communities—January 1, 1935

COUNTRY	Service Operated By (See Note)	NUMBER OF TELEPHONES In Communities of 50,000 Population and Over	NUMBER OF TELEPHONES In Communities of less than 50,000 Population	TELEPHONES PER 100 POPULATION In Communities of 50,000 Population and Over	TELEPHONES PER 100 POPULATION In Communities of less than 50,000 Population
Australia*	G.	293,477	207,925	9.07	6.04
Austria	G.	197,134	61,614	8.97	1.35
Belgium**	G.	227,133	96,290	6.43	2.03
Canada	P.G.	647,481	546,248	18.99	7.34
Czechoslovakia	P.G.	87,092	84,553	5.06	0.63
Denmark	P.	196,404	183,596	19.07	6.95
Finland	P.	54,141	86,926	11.00	2.66
France	G.	755,526	644,343	8.51	1.92
Germany†	G.	1,897,458	1,056,156	7.12	2.69
Great Britain and No. Ireland#	G.	1,740,600	676,000	6.59	3.33
Hungary	G.	92,679	29,123	4.53	0.43
Japan#	G.	699,811	368,433	3.51	0.76
Netherlands	G.	229,881	122,860	6.71	2.47
New Zealand#	G.	63,730	95,440	11.10	9.68
Norway*	P.G.	78,421	121,263	19.36	4.92
Poland	P.G.	122,452	88,882	2.46	0.31
Spain	P.	193,841	118,878	3.80	0.61
Sweden	G.	240,801	376,146	23.13	7.24
Switzerland	G.	173,861	209,428	19.76	6.41
Union of South Africa	G.	82,487	57,852	7.25	0.78
United States	P.	9,608,965	7,259,990	18.91	9.62

NOTE: P. indicates that the telephone service is wholly or predominantly operated by private companies, G. wholly or predominantly by the Government, and P.G. by both private companies and the Government. See first table.

* June 30, 1934. † March 31, 1934. ** February 28, 1935. # March 31, 1935.

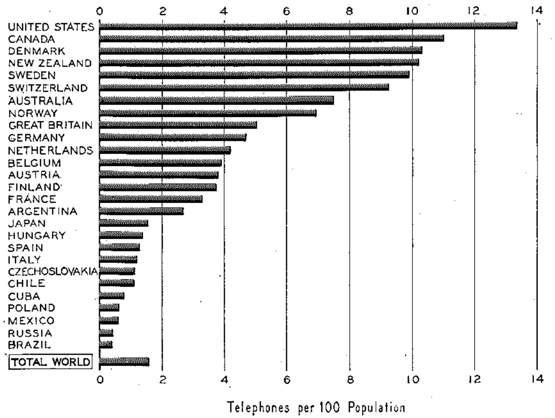
Telephone Conversations and Telegrams—Year 1934

COUNTRY	Number of Telephone Conversations	Number of Telegrams	Total Number of Wire Communications	PER CENT OF TOTAL WIRE COMMUNICATIONS Telephone Conversations	PER CENT OF TOTAL WIRE COMMUNICATIONS Telegrams	WIRE COMMUNICATIONS PER CAPITA Telephone Conversations	WIRE COMMUNICATIONS PER CAPITA Telegrams	WIRE COMMUNICATIONS PER CAPITA Total
Australia	428,000,000	14,051,000	442,051,000	96.8	3.2	64.3	2.1	66.4
Austria	600,000,000	1,689,000	601,689,000	99.7	0.3	88.7	0.2	88.9
Belgium	245,424,000	5,312,000	250,736,000	97.9	2.1	29.7	0.7	30.4
Canada	2,298,508,000	9,857,000	2,308,365,000	99.6	0.4	213.4	0.9	214.3
Czechoslovakia	270,000,000	3,860,000	273,860,000	98.6	1.4	17.8	0.3	18.1
Denmark	611,395,000	1,684,000	613,079,000	99.7	0.3	167.2	0.5	167.7
Finland	225,000,000	730,000	225,730,000	99.7	0.3	60.0	0.2	60.2
France	888,065,000	27,943,000	916,008,000	96.9	3.1	21.0	0.7	21.7
Germany	2,288,596,000	17,233,000	2,305,829,000	99.3	0.7	34.3	0.3	34.6
Great Britain and No. Ireland	1,720,000,000	43,926,000	1,763,926,000	97.5	2.5	36.9	0.9	37.8
Hungary	146,000,000	1,873,000	147,873,000	98.7	1.3	16.5	0.2	16.7
Japan	4,051,000,000	54,571,000	4,105,571,000	98.7	1.3	59.4	0.8	60.2
Netherlands	407,000,000	3,126,000	410,126,000	99.2	0.8	48.8	0.4	49.2
Norway	226,000,000	2,806,000	228,806,000	98.8	1.2	78.9	1.0	79.9
Poland	526,000,000	3,164,000	529,164,000	99.4	0.6	15.8	0.1	15.9
Spain	735,000,000	24,393,000	759,393,000	96.8	3.2	30.2	1.0	31.2
Sweden	900,000,000	3,592,000	903,592,000	99.6	0.4	144.6	0.6	145.2
Switzerland	278,335,000	1,857,000	280,192,000	99.3	0.7	67.3	0.5	67.8
Union of South Africa	247,000,000	5,529,000	252,529,000	97.8	2.2	29.0	0.7	29.7
United States	24,250,000,000	160,000,000	24,410,000,000	99.3	0.7	192.4	1.3	193.7

NOTE: Telephone conversations represent completed local and toll or long distance messages. Telegrams include inland and outgoing international messages.

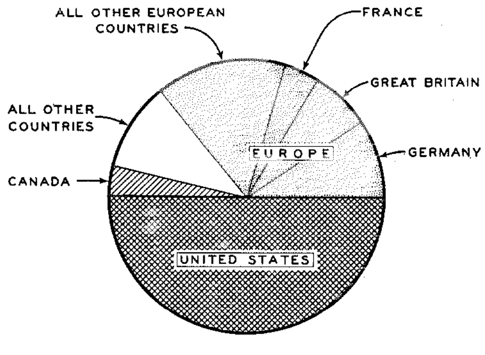
TELEPHONES PER 100 POPULATION

January 1, 1935



DISTRIBUTION OF THE WORLD'S TELEPHONES

January 1, 1935

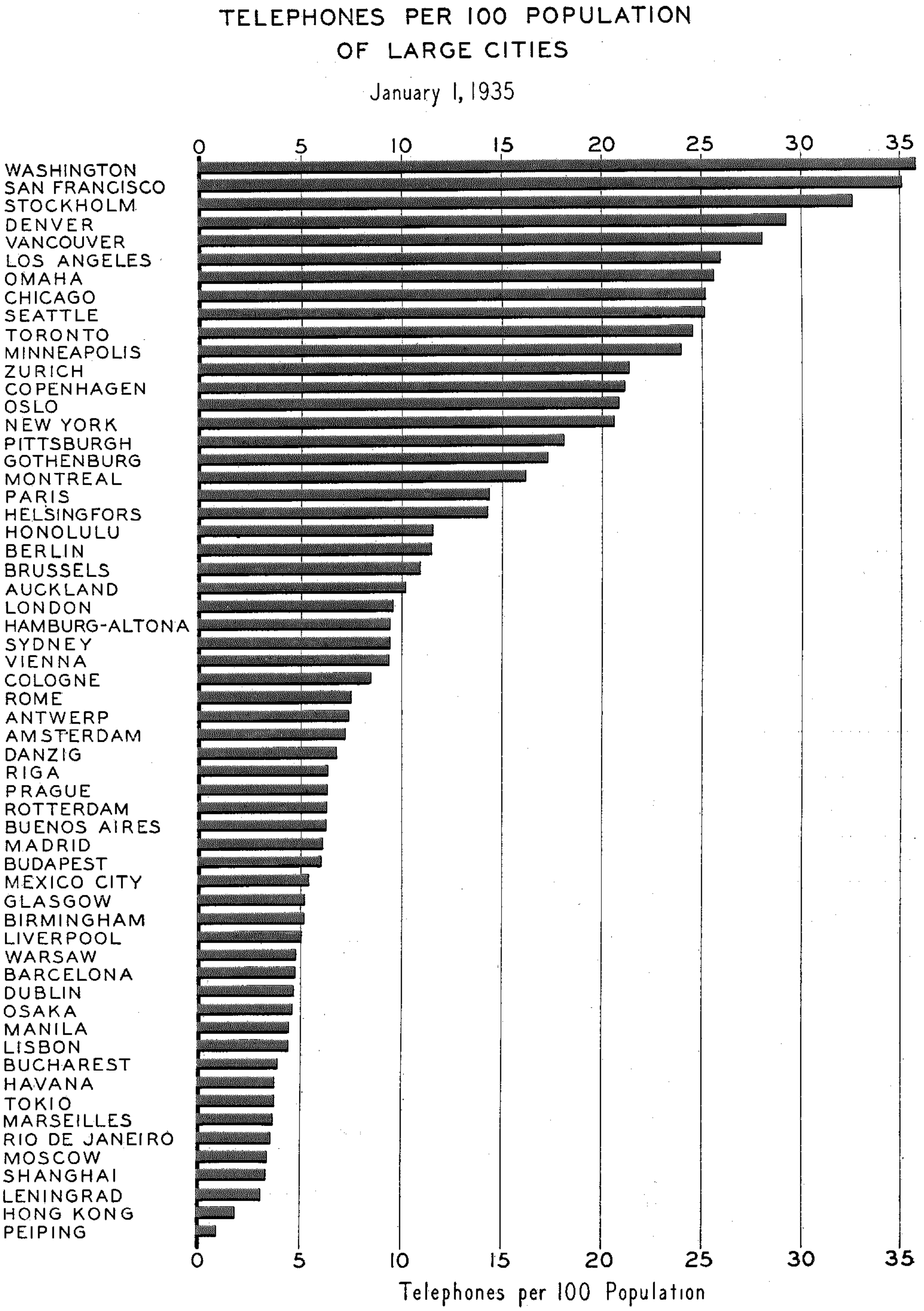


Telephone Development of Large Cities
January 1, 1935

Country and City (or Exchange Area)	Estimated Population (City or Exchange Area)	Number of Telephones	Telephones Per 100 Population
ARGENTINA:			
Buenos Aires	3,000,000	188,528	6.28
AUSTRALIA:			
Adelaide	314,000	28,949	9.22
Brisbane	305,000	26,707	8.76
Melbourne	1,000,000	103,137	10.31
Sydney	1,249,000	117,759	9.43
AUSTRIA:			
Graz	153,000	10,784	7.05
Vienna	1,875,000	175,947	9.38
BELGIUM:**			
Antwerp	530,000	39,228	7.40
Brussels	965,000	105,654	10.95
Liege	424,000	23,695	5.59
BRAZIL:			
Rio de Janeiro	1,800,000	64,046	3.56
CANADA:			
Montreal	1,016,700	164,594	16.19
Ottawa	188,000	35,441	18.85
Toronto	766,300	188,287	24.57
Vancouver	187,500	52,549	28.03
CHINA:			
Canton	1,060,000	8,056	0.76
Hong Kong	850,000	14,845	1.75
Peiping	1,540,000	12,948	0.84
Shanghai††	1,650,000	54,861	3.32
CUBA:			
Havana	700,000	25,899	3.70
CZECHOSLOVAKIA:			
Prague	913,000	57,725	6.32
DANZIG:			
Free City of Danzig	265,000	17,964	6.78
DENMARK:			
Copenhagen	820,000	173,372	21.14
FINLAND:			
Helsingfors	270,000	38,653	14.32
FRANCE:			
Bordeaux	268,000	20,348	7.59
Lille	202,000	17,346	8.59
Lyons	670,000	35,317	5.27
Marseilles	930,000	34,165	3.67
Paris	2,905,000	416,870	14.35
GERMANY:#			
Berlin	4,250,000	488,244	11.49
Breslau	630,000	42,185	6.70
Cologne	765,000	64,935	8.49
Dresden	735,000	60,899	8.29
Dortmund	585,000	23,958	4.10
Essen	665,000	30,254	4.55
Frankfort-on-Main	655,000	61,968	9.46
Hamburg-Altona	1,650,000	155,826	9.44
Leipzig	775,000	65,038	8.39
Munich	745,000	79,219	10.63
GREAT BRITAIN AND NO. IRELAND:#			
Belfast	415,000	19,280	4.65
Birmingham	1,210,000	62,147	5.14
Bristol	417,000	22,711	5.45
Edinburgh	444,000	34,565	7.78
Glasgow	1,195,000	61,747	5.17
Leeds	514,000	25,922	5.04
Liverpool	1,200,000	60,131	5.01
London	9,300,000	891,725	9.59
Manchester	1,103,000	67,336	6.10
Newcastle	471,000	20,558	4.36
Sheffield	520,000	21,202	4.08
HAWAII:			
Honolulu	138,000	15,942	11.55
HUNGARY:			
Budapest	1,360,000	81,886	6.02
Szeged	138,000	2,100	1.52
IRISH FREE STATE:#			
Dublin	429,000	19,920	4.64
ITALY:			
Milan	1,065,000	88,701	8.33
Naples	880,000	27,098	3.08
Rome	1,150,000	86,393	7.51
JAPAN: #			
Kobe	854,000	34,700	4.06
Kyoto	1,053,000	42,408	4.03
Nagoya	1,018,000	34,846	3.42
Osaka	2,723,000	124,883	4.59
Tokio	5,663,000	209,605	3.70
LATVIA:#			
Riga	385,000	24,437	6.35
MEXICO:			
Mexico City	1,150,000	61,969	5.39
NETHERLANDS:			
Amsterdam	782,000	56,468	7.22
Haarlem	162,000	12,775	7.89
Rotterdam	616,000	38,808	6.30
The Hague	518,000	48,939	9.45
NEW ZEALAND:#			
Auckland	218,000	22,236	10.20
NORWAY:*			
Oslo	250,000	52,198	20.88
PHILIPPINE ISLANDS:			
Manila	394,000	17,328	4.40
POLAND:			
Lodz	900,000	14,356	1.60
Warsaw	1,260,000	59,842	4.75
PORTUGAL:			
Lisbon	651,000	28,470	4.37
ROUMANIA:			
Bucharest	640,000	24,718	3.86
RUSSIA:			
Leningrad	3,000,000	91,023	3.03
Moscow	4,000,000	134,440	3.36
SPAIN:			
Barcelona	1,080,000	51,014	4.72
Madrid	1,000,000	61,017	6.10
SWEDEN:			
Gothenburg	255,000	44,228	17.32
Malmö	139,000	21,591	15.56
Stockholm	441,000	144,011	32.64
SWITZERLAND:			
Basel	151,000	32,441	21.48
Berne	114,000	24,992	21.92
Geneva	147,000	27,235	18.53
Zurich	268,000	57,330	21.39
UNITED STATES: (See Note)			
New York	7,247,000	1,493,374	20.61
Chicago	3,270,000	824,293	25.21
Los Angeles	1,315,000	341,221	25.95
Pittsburgh	1,015,900	183,761	18.09
Total 10 cities over 1,000,000 Population	21,777,600	4,437,758	20.38
Milwaukee	763,200	135,963	17.81
San Francisco	690,000	242,026	35.08
Washington	528,000	189,017	35.80
Minneapolis	505,000	121,123	23.98
Total 10 cities with 500,000 to 1,000,000 Population	6,515,300	1,320,692	20.27
Seattle	417,200	105,087	25.19
Denver	300,000	87,755	29.25
Omaha	238,600	61,186	25.64
Hartford	237,300	53,224	22.43
Total 34 cities with 200,000 to 500,000 Population	10,191,900	1,812,160	17.78
Total 54 cities with more than 200,000 Population	38,484,800	7,570,610	19.67

NOTE: There are shown, for purposes of comparison with cities in other countries, the total development of all cities in the United States in certain population groups, and the development of certain representative cities within each of such groups.

* June 30, 1934. ** February 28, 1935. # March 31, 1935. †† International Settlement and French Concession.


TELEPHONES PER 100 POPULATION
OF LARGE CITIES
January 1, 1935
0
5
10
15
20
25
30
35
WASHINGTON
SAN FRANCISCO
STOCKHOLM
DENVER
VANCOUVER
LOS ANGELES
OMAHA
CHICAGO
SEATTLE
TORONTO
MINNEAPOLIS
ZURICH
COPENHAGEN
OSLO
NEW YORK
PITTSBURGH
GOTHENBURG
MONTREAL
PARIS
HELSINGFORS
HONOLULU
BERLIN
BRUSSELS
AUCKLAND
LONDON
HAMBURG-ALTONA
SYDNEY
VIENNA
COLOGNE
ROME
ANTWERP
AMSTERDAM
DANZIG
RIGA
PRAGUE
ROTTERDAM
BUENOS AIRES
MADRID
BUDAPEST
MEXICO CITY
GLASGOW
BIRMINGHAM
LIVERPOOL
WARSAW
BARCELONA
DUBLIN
OSAKA
MANILA
LISBON
BUCHAREST
HAVANA
TOKIO
MARSEILLES
RIO DE JANEIRO
MOSCOW
SHANGHAI
LENINGRAD
HONG KONG
PEIPING
0
5
10
15
20
25
30
35
Telephones per 100 Population

Licensee Companies

Bell Telephone Manufacturing Company	*Antwerp, Belgium*
Branches: Brussels.	
Bell Telephone Manufacturing Company	*Berne, Switzerland*
Bell Telephone Manufacturing Company	*The Hague, Holland*
China Electric Company, Limited	*Shanghai, China*
Branches: Canton, Hankow, Hongkong, Peiping, Tientsin.	
Compañía Radio Aerea Maritima Española	*Madrid, Spain*
Compañía Standard Electric Argentina	*Buenos Aires, Argentina*
Creed and Company, Limited	*Croydon, England*
Fabbrica Apparecchiature per Comunicazione Elettriche	*Milan, Italy*
International Marine Radio Company, Limited	*London, England*
International Standard Electric Corporation, *Branch Office,*	*Rio de Janeiro, Brazil*
Jugoslavian Standard Electric Company, Limited	*Belgrade, Jugoslavia*
Kolster-Brandes, Limited	*Sidcup, England*
Le Matériel Téléphonique	*Paris, France*
Branch: Rabat, Morocco.	
Nippon Denki Kabushiki Kaisha	*Tokyo, Japan*
Branches: Osaka, Dairen, Taihoku.	
Société Anonyme les Téléimprimeurs	*Paris, France*
Standard Electric Aktieselskab	*Copenhagen, Denmark*
Standard Electric Company w Polsce Ska z O. O.	*Warsaw, Poland*
Standard Electric Doms a Spol	*Praha, Czechoslovakia*
Branch: Bratislava.	
Standard Electrica	*Lisbon, Portugal*
Standard Electrica Románá, S.A.	*Bucharest, Rumania*
Standard Eléctrica, S.A.	*Madrid, Spain*
Branches: Barcelona, Santander.	
Standard Elektrizitäts-Gesellschaft A.G.	*Berlin, Germany*
Standard Elettrica Italiana	*Milan, Italy*
Branch: Rome.	
Standard Telefon-og Kabelfabrik A/S	*Oslo, Norway*
Standard Téléphone et Radio, S.A. Zürich	*Zürich, Switzerland*
Standard Telephones and Cables, Limited	*London, England*
Branches: Glasgow, Leeds, Dublin, Cairo, Pretoria, Calcutta.	
Standard Telephones and Cables (Australasia), Limited	*Sydney, Australia*
Branches: Melbourne; Wellington, New Zealand.	
Standard Villamossági Részvény Társaság	*Budapest, Hungary*
Sumitomo Electric Wire & Cable Works, Limited	*Osaka, Japan*
Vereinigte Telephon- und Telegraphenfabriks Aktien-Gesellschaft, Czeija, Nissl & Co.	*Vienna, Austria*

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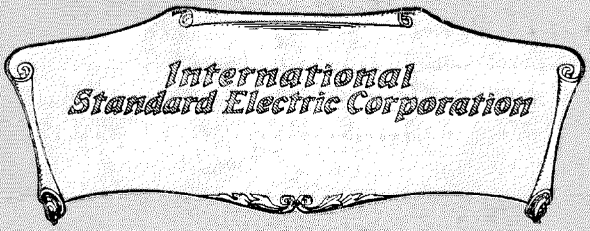

International
Standard Electric Corporation

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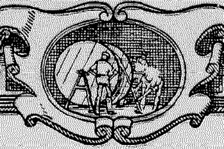

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OCTOBER No. 2

1936 VOL. 15

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H. T. KOHLHAAS, Editor

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PLANT OF
COMPAGNIE DES TÉLÉPHONES THOMSON-HOUSTON
PARIS, FRANCE

A Field Trial of 50 Cycle Signaling on Toll Lines

By WILLIAM HATTON,

Chief Engineer, Switching Systems, Bell Telephone Manufacturing Company, Antwerp, Belgium

General

THE introduction of full automatic equipment for rural and suburban exchanges and the rapid progress of subscriber-to-subscriber dialing over toll lines during recent years has necessitated a departure from the familiar methods of direct current signaling in use on the shorter junctions between urban exchanges.

Signaling with direct current can only be applied economically to lines not exceeding a certain resistance, the maximum value being determined by the operating current of the signaling relays. This maximum is generally about 1,400 ohms. Further, direct current methods of signaling are unsuitable for lines which are phantomed or equipped with repeaters.

It is interesting to note in passing that direct current signaling circuits are usually simple, the current remaining connected to line as long as required to maintain a given signal. This is not possible with alternating currents of frequencies within audible range without interfering with conversation. The signals are therefore transmitted as short impulses and each impulse indicates a change of condition. Speech currents must not cause the operation of the signaling system.

50 cycle alternating current has been in use for a number of years for signaling and dialing on toll lines, but the results obtained have not been entirely satisfactory and suffered from two major defects: firstly, the sending voltage required was too high, thereby causing interference with neighbouring circuits; and, secondly, the impulses were distorted.

A new type of 50 cycle signaling system has been developed by the Laboratories of the Bell Telephone Manufacturing Company, Antwerp. It operates with low sending voltage and current, thus preventing excessive distortion of the impulses while retaining a circuit of simple form and low transmission loss.

Early this year, a complete demonstration of the rotary automatic toll system was made in Berne for the officials of the Swiss P. T. T. The demonstration equipment was later installed in the towns of Faido, Lugano, and Zurich in order to test the 50 cycle alternating current signaling under service conditions. The test was continued without interruption for two months.

Thanks are due to the officials of the Swiss P. T. T. for making it possible to conduct this field trial and for their generous cooperation throughout. The new type 50 cycle signaling system, described in this article, has been accepted as standard for Switzerland.

The Field Trial

An 800 km. two-wire cable circuit was established between Faido and Zurich, as shown in Fig. 1. At Lugano and Zurich, equipment was installed to represent tandem toll switching points (see Tandem Units A and B—Fig. 1) with standard two-wire repeaters automatically connected and with regulation of the gain also automatic. Four additional repeaters were connected permanently in the line, thus making a total of six standard two-wire repeaters in circuit.

In addition to successfully demonstrating the numerous important facilities of the Rotary Automatic Toll System described in *Electrical Communication*, January, 1934, the field trial under most stringent conditions showed the impressive regularity with which the new 50 cycle system operated. The trial was made by sending commercial calls from Faido to Zurich, the toll operator at Faido dialing over the 800 km. circuit into the Zurich city and rural networks.

During the first ten days of the trial, 2,700 commercial calls were made with a total of thirteen faults, representing 0.48%. This percentage of faults is not greater than that found in the average local network. The trial circuit included:

(*a*) An outgoing toll exchange: Faido,
(*b*) A tandem toll exchange: Lugano,
(*c*) A second tandem toll exchange: Zurich,
(*d*) A terminating toll exchange: Zurich,
(*e*) A local automatic exchange,
(*f*) Six standard two-wire repeaters.

Fig. 2 shows one of the three demonstration units.

The concluding paragraph of the Official Report of the Swiss Administration, dated May 11, 1936, is of great interest and reads as follows:

> The field trial has demonstrated that it is possible to establish connections with the Canton of Tessin, employing tandem toll switching and standard two-wire repeaters adjusted to give an overall loss of 1 neper. From all points of view, the trial represented an extreme case, the total length of the circuit being approximately 800 km., composed of physical and phantom sections.
>
> The transmission of impulses with the new receiving unit did not present the slightest difficulty. The correction of impulses (when necessary) could be made very easily and without the addition of numerous relays.
>
> The model demonstrated that the automatic introduction of switched repeaters is possible, not only on paper but is practical, and that exploitation is possible without adding to the number of faults normally admitted for a telephone exchange.

Three different applications of the signaling system were demonstrated, as follows:

(1) To a toll line terminating in the Zurich network,
(2) To a toll line at a tandem point with switched repeater (Lugano and Zurich),
(3) To a permanent repeater (loop circuits between Zurich and Niederurnen and at Faido).

The impulse receiving unit is the same in all three applications.

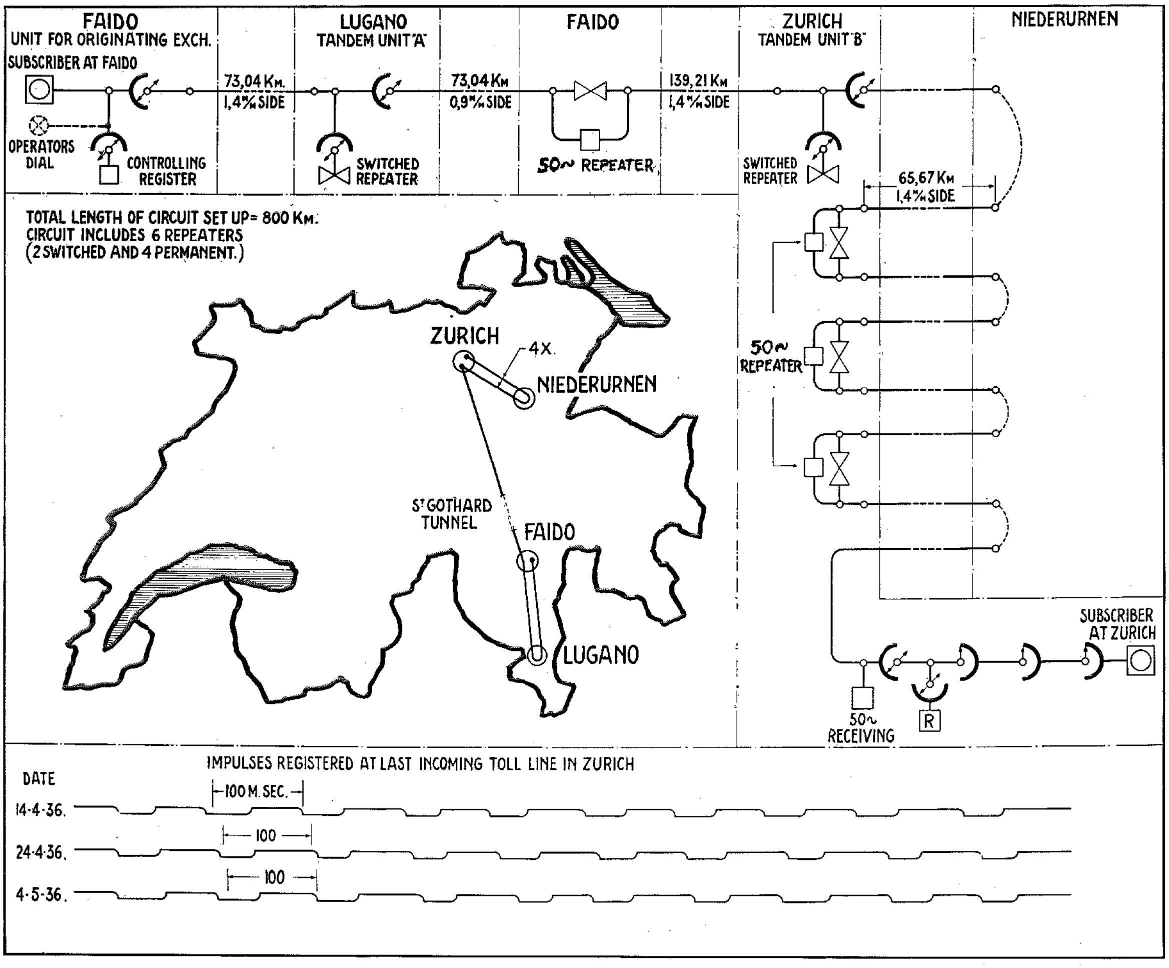

Fig. 1—Trial Circuit Set Up in Switzerland.

Application to Terminating Line (See Fig. 3)

(1) A transformer T shown connected to the toll line over the back contact of relay Er.

(2) A condenser $C1$ connected in series with the primary winding of T.

(3) A rectifier Rc connected to the secondary of T.

(4) An impulse receiving relay Rr which is polarised. The left-hand winding of Rr is connected through test jack TJ to the rectifier Rc, and the right-hand winding at one end to battery in series with condenser $C2$ and resistance $R2$. The other end of the winding is connected to the front contact of Rr.

(5) An impulsing relay Mr, which really forms part of the local equipment. One end of the winding of Mr is connected to the front contact of Rr in parallel with resistance $R3$.

When a 50 cycle current impulse is received, it passes over the back contacts of relay Sr, the condenser $C1$ and the primary winding of transformer T. A current is induced in the secondary of T which is rectified by Rc and operates Rr over its left-hand winding. Rr by its front contact operates Mr which causes the local automatic equipment to respond to the received impulse.

Elimination of Chattering and Distortion

Formerly, one of the most pronounced objections to the use of 50 cycle alternating current was the fact that the receiving relay had a tendency to follow the sinusoidal variations of the 50 cycle current, which caused chattering of the front contact and distortion of the impulse. This phenomenon was very marked in the early circuits employing alternating current relays and, moreover, since it occurred irregularly it was very difficult to correct by any form of impulse corrector.

It must be kept in mind that even the rectified current which flows through the left-hand winding of Rr has "upper" and "lower" peaks and, should the relay operate at an "upper" peak, there is a tendency to release again when the current drops to the "lower" peak.

To prevent such chattering, the impulsing relay Rr has been provided with a second winding connected in series with condenser $C2$ and resistance $R2$ to battery. When Rr makes its front contact for the first time, condenser $C2$ commences to charge and current flows through the second winding of the relay which helps the magnetic flux to develop and renders the front contact pressure less dependent on the variation of current in the left-hand winding.

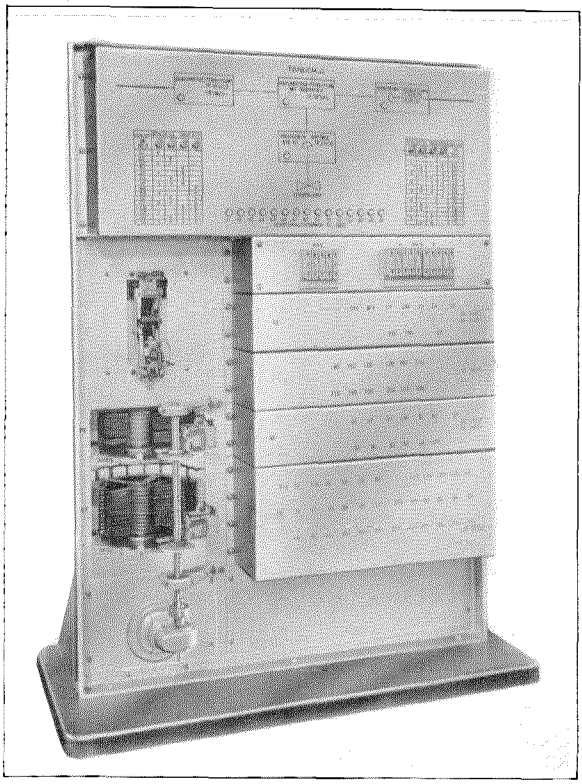

Fig. 2—One of Three Demonstration Models.

When Rr opens its front contact, $C2$ discharges and a reverse magnetic flux is built up, which assists the deenergisation. It is of interest to note here that in earlier circuits employing rectifiers and impulse relays with single windings, special precautions were required to eliminate the shunt effect of the rectifier and the tendency of the relay to be slow releasing, a most undesirable condition for good impulsing.

The discharge of $C2$ not only helps the deenergisation of Rr but, should the interval between two successive impulses be very short, it delays the reoperation of Rr. In this manner, the impulses transmitted from the front contact of Rr to the local circuit relay Mr are corrected

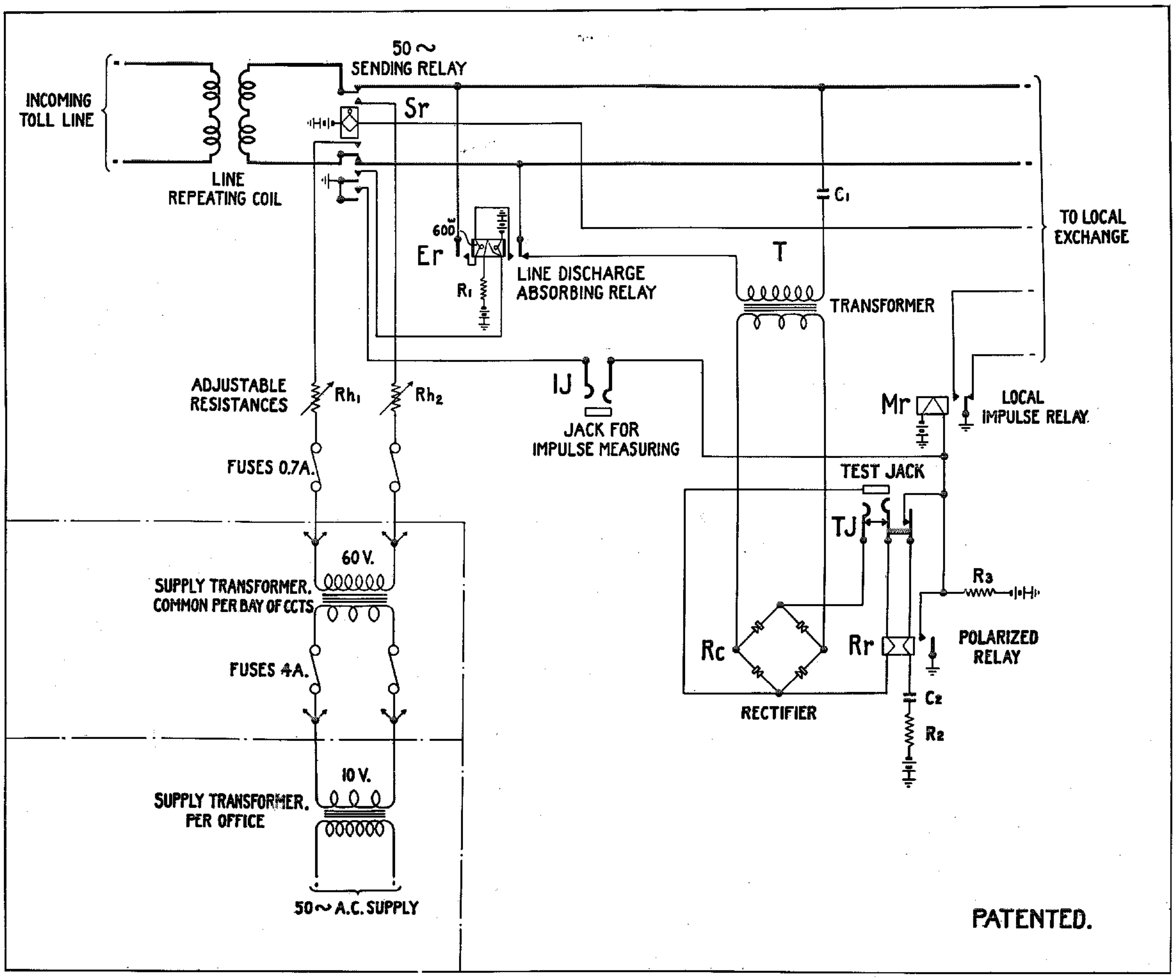

Fig. 3—Terminating Toll Line.

and the successive openings and closures properly spaced.

If it is found desirable to change the ratio of the impulse given by the front contact of *Mr*, it can be done by varying the shunt resistance *R*3.

The combination of polarised relay with two windings, condenser *C*2 and resistance *R*2, is the most important contribution towards the elimination of irregularities so noticeable in other 50 cycle circuits. Oscillograms show that *Rr* transmits a steady and uniform impulse. Fig. 4 is taken from an oscillogram showing the front contact closure of *Rr*.

The chief characteristics of this new receiving unit can be summarised as follows:

(1) Elimination of chatter of front contact of impulsing relay due to the sinusoidal variation of the 50 cycle alternating current;
(2) Elimination of "kick" or rebound of armature of impulsing relay;
(3) Correction of impulse for both closure and opening;
(4) Means to vary impulse ratio to suit local conditions;
(5) The use of a transformer permits the impedance of the receiving circuit to be as low as is necessary for good impulsing without increasing the transmission loss;
(6) Robust and simple equipment, requiring little maintenance.

Operating Requirements

When connected, as shown in Fig. 3, the receiving unit will impulse correctly over a circuit of 70 km. of 0.9 mm. (H-177) loaded cable with the voltage at the sending end adjusted to 32 volts and a current of 0.017 ampere. Under these conditions, the voltage measured across the terminals of the primary of *T* is 11 volts and the current in the left-hand winding of *Rr* is 0.014 ampere.

Transmission Loss

An important feature of the circuit is the fact that the receiving unit, although bridged across the line, causes practically no transmission loss. The impedance presented to voice currents is of the order of 35,000 ohms.

This is due to the fact that it is possible to tune the receiving unit to 50 cycle current by means of the condenser *C*1 and to the action of the rectifier *Rc*.

It is a well known characteristic of selenium rectifiers that the resistance is to a certain extent a function of the current. At speech currents of average level, the resistance of *Rc* is high and the secondary winding of the transformer *T* is practically open.

The high impedance presented to voice currents makes it unnecessary to modify the balancing network of the line. This is important when the receiving unit is used at tandem points where it may be necessary to connect a repeater.

Interference

In practice it was found that, even with the low sending voltage of 32 volts, clicks were still audible on adjacent circuits. After a series of measurements in the field, the cause of this interference was traced to longitudinal currents due to the unbalance in the leads supplying the 50 cycle current. It was found that the clicks could be practically eliminated by introducing an individual or semi-common transformer in the supply circuit. Using the individual transformer, field tests showed that the interference measured on adjacent circuits was negligible.

Damping of Cable Discharge

The 50 cycle current is connected to line over the front contacts of relay *Sr* which, at the same time, disconnects the receiving unit. The voltage is adjusted to the correct value by means of the series resistances *Rh*1 and *Rh*2. When *Sr* deenergises, the capacity discharge of the line is prevented from reaching the receiving unit by means of relay *Er*. When *Sr* operates, it completes a circuit for *Er* which disconnects the primary winding of transformer *T* from the line and connects in place a 600 ohm non-inductive resistance. *Er* is slow releasing and remains operated during the transmission of dial impulses, whereas *Sr* operates and releases once for each impulse.

Each time *Sr* deenergises, the line discharges through the 600 ohm non-inductive resistance connected over the front contacts of *Er*.

Application to a Tandem Toll Line (See Fig. 5)

When connected across a toll line, arranged for tandem working, the receiving unit proper is exactly the same as that shown in Fig. 3. In this application the unit has a number of addi-

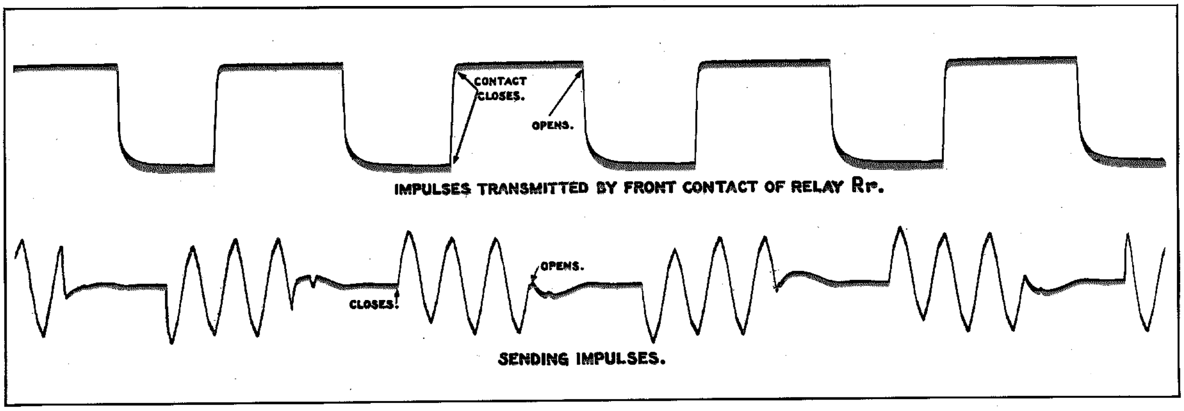

Fig. 4—Oscillogram of Front Contact of Relay Rr.

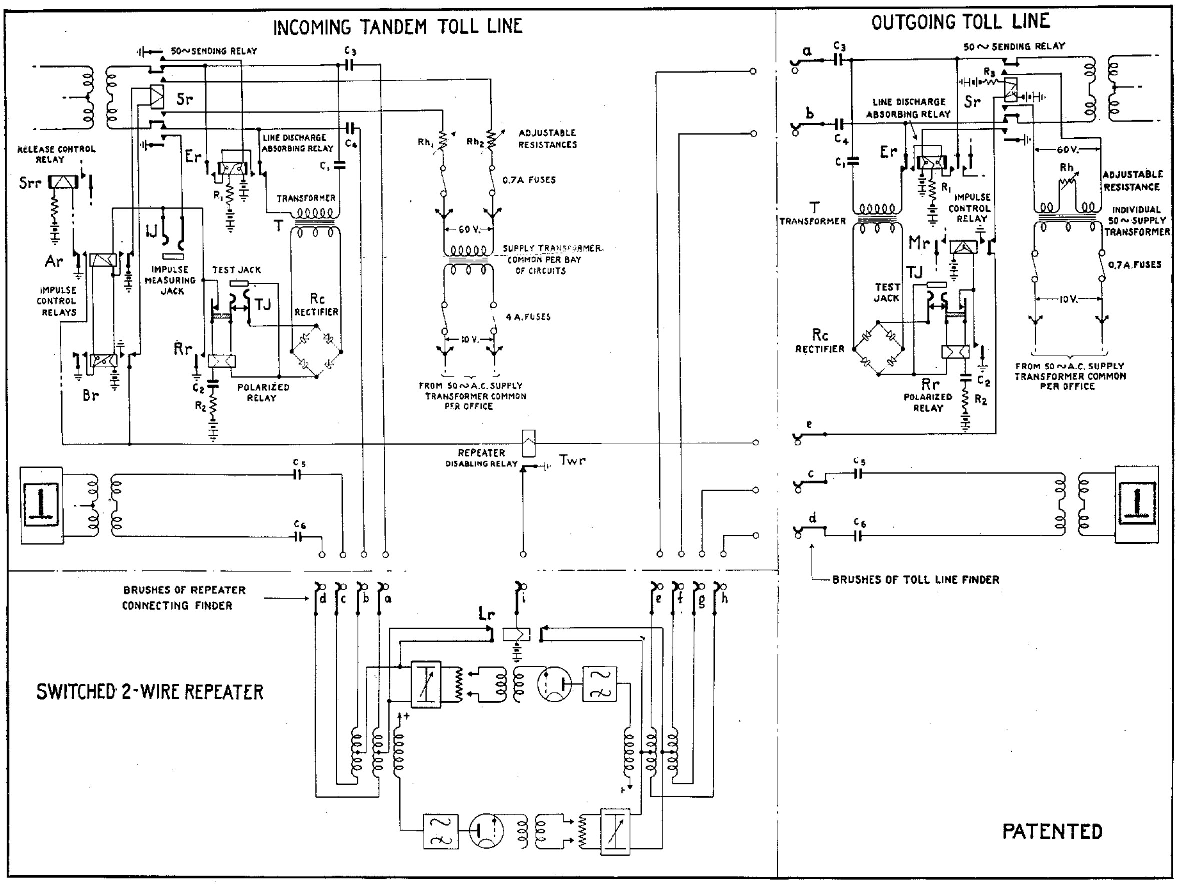

Fig. 5—Tandem Toll Line.

tional functions, among which are the control of a local selection in order to choose the required direction, the disabling of a switched repeater during impulsing, and the repetition of the impulses to the following toll line.

The circuit includes two additional relays, *Ar* and *Br*, which are operated from *Rr* and which carry the contacts necessary to perform the above-mentioned functions. These relays also help to maintain the impulse at a minimum length and prevent any distortion which may be present due to the influence of the additional relay *Twr*.

The left-hand side of the diagram shows the incoming end of a toll line arranged for tandem working, and the right-hand side a regular outgoing toll line. The lower portion of the diagram shows the elements of a standard two-wire repeater arranged for automatic switching and automatic gain control.

When a 50 cycle impulse arrives at the incoming line, relays *Rr*, *Ar*, and *Br* operate. *Br* completes a circuit for *Sr* which connects 50 cycle current to the outgoing toll line. *Twr* operates in series with *Sr* and closes a circuit for *Lr* in the switched repeater circuit, thereby disabling the repeater during the transmission of impulses. *Twr* also operates when an impulse is sent in the reverse direction, namely, from the outgoing line to the incoming line. In this case, *Rr* of the outgoing line operates *Mr* which, in turn, closes a circuit for *Sr* of the incoming line.

The complete equipment of an incoming toll line arranged for tandem working and switched repeater is shown in Fig. 7.

Application to a Line Repeater (See Fig. 6)

Fig. 6 shows the elements of a standard two-wire repeater and, in the centre of the diagram, two 50 cycle units, associated with the east and west sides of the repeater.

In this application, the transformers *T*1 and *T*2 are connected across the centre points of the east and west hybrid coils, respectively. The rectifiers *Rc*1 and *Rc*2, together with the polarised relays *Rr*1 and *Rr*2, are connected in exactly the same manner as described for the previous applications. The function of the 50 cycle units, in this case, is to relay the received impulse from one side of the repeater to the other; and it will be seen that *Rr*1, associated with the west line, operates relay *Sr*2 which sends out 50 cycle alternating current to the east line. In the reverse direction, *Rr*2 operates *Sr*1 which sends out 50 cycle to the west line.

Tracing the circuit in detail, it will be seen that, when a 50 cycle current impulse arrives

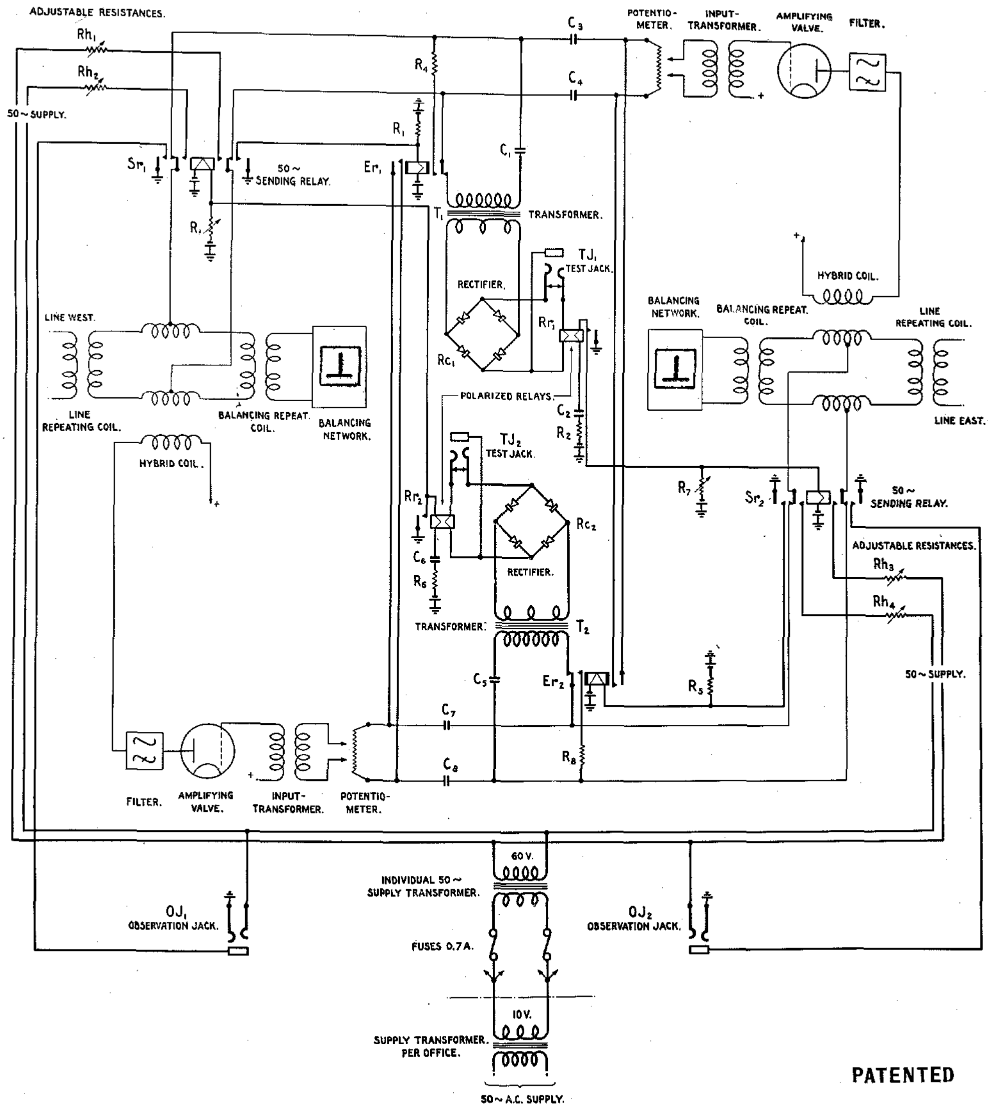

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Fig. 6—Line Repeater.

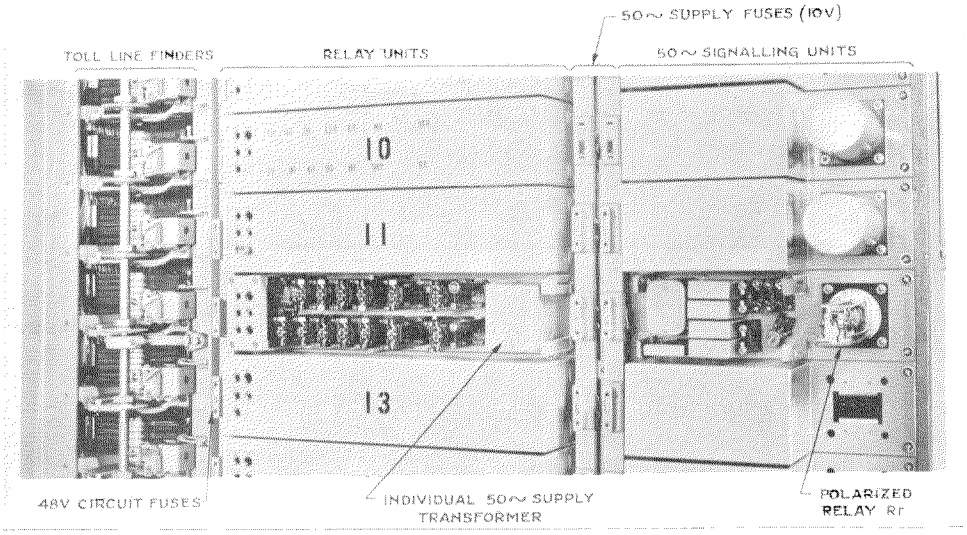

Fig. 7—Complete Equipment of Tandem Toll Line.

from the west line, it passes over the back contacts of relay *Sr*1, the condenser *C*1 and the primary of transformer *T*1. A current is induced in the secondary of the transformer, which is rectified by *Rc*1 and passes through the left-hand winding of relay *Rr*1. From the front contact of *Rr*1, a circuit is closed for *Sr*2 which operates and connects 50 cycle current to the east line.

A second circuit in parallel with the primary winding of transformer *T*1 includes the two condensers *C*3 and *C*4 and the potentiometer of the repeater. The two condensers are chosen to render the impedance of this parallel circuit high to 50 cycle alternating current with the object of preventing the amplifying valve of the repeater from being influenced by the signaling current. Should this occur, it might be possible for the repeater to transmit to the east line 50 cycle current or harmonics which would not be in phase with the current sent from the front contact of *Sr*2 and which would, therefore, adversely influence the receiving unit at the next point along the line. To definitely prevent such interference, the potentiometer is short-circuited by a front contact of *Er*2 which is operated from *Sr*2. Further, *Er*2 is slow releasing and has the function of connecting a resistance to absorb the line discharges which occur when *Sr*2 makes its back contact.

When connected in this manner to a standard two-wire repeater, it will be seen that part of the received current is absorbed by the balancing network and, to compensate for this, the sending voltage at the distant end must be raised.

When sending over 80 km. of 0.9 mm. (H-177) loaded cable, the sending voltage required is 49 volts and the current is 0.017 ampere.

Generalised Characteristics of Linear Networks

By E. K. SANDEMAN

LINEAR electrical networks consisting of inductances, capacitances, and resistances are employed among other purposes to supply characteristics which vary with the frequency of the applied electrical oscillations.

When the characteristics of interest are impedance, attenuation, and phase shift, it is evident that by changing the absolute values of the elements of inductance, capacitance, and resistance, a given form of characteristic, expressed as a function of frequency, may be obtained within practical limits in any required range of absolute frequency. Further, a network designed, for instance, to afford a variation of attenuation with frequency, may be arranged to give the same attenuation curve as a function of frequency, when operating between any values of impedance lying within a practical range of impedances determined by the limitations of design of the component elements and of the associated circuits. Evidently the performance of any specific embodiment of such a network is specifiable uniquely by a specific curve of attenuation against frequency, this curve being valid only for given absolute values of terminating impedance. An infinite number of infinite series of curves are therefore required to specify the performance of the whole group of embodiments of a single form of attenuating network.

As will be seen by reference to any work on filter theory it is well known that, when the relations between the elements are fixed by means of a simple process of disembodiment, the performance of the whole group of networks of a given form can be determined by a single curve for each characteristic required.

Although the present purpose is mainly to present a series of such characteristics, the use of these characteristics will be made clearer by a preliminary discussion of their method of derivation for the benefit of those to whom the method is not familiar.

Two-Terminal Networks

Such networks are usually employed to afford an impedance in which the resistive and reactive components vary with frequency in some prescribed way.

Fig. 1 shows six two-element networks for which generalised characteristics have been derived. Consider the network type 1 of Fig. 1: Its impedance at any angular frequency ω is given by

$$Z=\frac{RLj\omega}{R+Lj\omega}=\frac{RLj\omega(R-Lj\omega)}{R^2+L^2\omega^2};$$

$$\therefore Z=\frac{RL^2\omega^2}{R^2+L^2\omega^2}+j\frac{R^2L\omega}{R^2+L^2\omega^2}. \tag{1}$$

Define f_0 as the frequency at which the reactance of L in ohms equals the numerical value of R in ohms and make $\omega_0=2\pi f_0$; then

$$L\omega_0=R \quad\text{and}\quad L=\frac{R}{\omega_0}. \tag{2}$$

Substituting (2) in (1),

$$Z=\frac{R\cdot R^2\dfrac{\omega^2}{\omega_0^2}}{R^2+R^2\dfrac{\omega^2}{\omega_0^2}}+j\frac{R^2R\dfrac{\omega}{\omega_0}}{R^2+R^2\dfrac{\omega^2}{\omega_0^2}}$$

$$=R\left[\frac{\dfrac{\omega^2}{\omega_0^2}}{1+\dfrac{\omega^2}{\omega_0^2}}+j\frac{\dfrac{\omega}{\omega_0}}{1+\dfrac{\omega^2}{\omega_0^2}}\right], \tag{3}$$

$$=R[Y+jX], \text{ say.}$$

Evidently the quantity within the brackets is characteristic of the impedance of all possible networks of this type. If the real and the imaginary parts of the quantity inside the brackets are plotted as a function of ω/ω_0, the resultant curves afford a rapid means of determining the impedance characteristics of any specific embodiment of the network by assigning values to R and L and so to

$$\omega_0=\frac{R}{L} \quad\text{and}\quad f_0=\frac{R}{2\pi L}.$$

Fig. 2 shows a plot of the functions Y and X dependent on ω/ω_0.

$$Y=\frac{\dfrac{\omega^2}{\omega_0^2}}{1+\dfrac{\omega^2}{\omega_0^2}} \quad\text{and}\quad X=\frac{\dfrac{\omega}{\omega_0}}{1+\dfrac{\omega^2}{\omega_0^2}}.$$

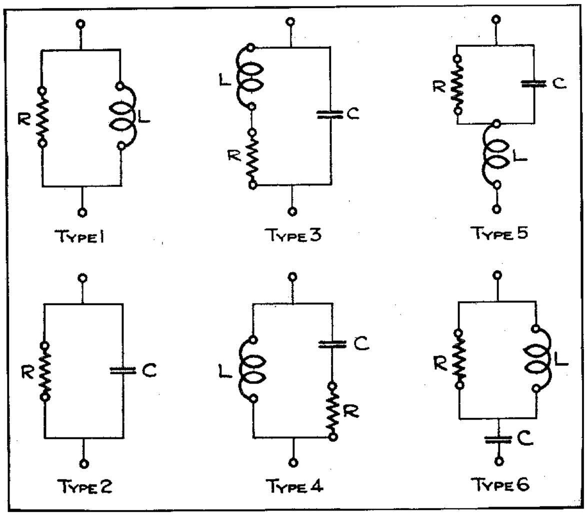

Fig. 1—Classification of Six Most Simple Networks Containing a Single Resistance.

It will be noted that

$$\frac{\omega}{\omega_0}=\frac{2\pi f}{2\pi f_0}=\frac{f}{f_0}.$$

Example.

Determine from Fig. 2 the impedance characteristic of a network of type 1 in which $L=1$ Henry and $R=1000$ ohms.

$$f_0=\frac{R}{2\pi L}=\frac{1000}{2\pi}=159.$$

Hence, when $f=159$, $\frac{f}{f_0}=\frac{\omega}{\omega_0}=1$;

when $f=318$, $\frac{f}{f_0}=\frac{\omega}{\omega_0}=2$;

when $f=79.5$, $\frac{f}{f_0}=\frac{\omega}{\omega_0}=0.5$, etc.

The absolute frequency scale can therefore be determined by writing 159 against $\omega/\omega_0=1$ on Fig. 2, 318 against $\omega/\omega_0=2$, 79.5 against $\omega/\omega_0=0.5$, etc.

In practice, of course, this cumbersome method is never adopted. Plotting is carried out to a logarithmic frequency scale as in Fig. 2, so that it is only necessary to have a scale of absolute frequency plotted on the same kind of paper in a manner such that equal ratios on both scales (i.e., the scale of absolute frequency and the scale of ω/ω_0 in Fig. 2) are represented by equal intervals. In this case, by sliding the two scales so that the frequency 159 comes opposite $\omega/\omega_0=1$, the curves of Fig. 2 have direct application to the scale of absolute frequency.

The values of resistance and reactance are then given by 1000 Y and 1000 X. The values of reactance and resistance are shown for three values of f in the table below.

f	Y	Network Resistance Ohms	X	Network Reactance Ohms
79.5	0.2	200	0.4	400
159	0.5	500	0.5	500
318	0.8	800	0.4	400

In the case of networks containing more than two elements, it is necessary to introduce extra parameters determining the relations between the elements, the number of parameters being always one less than the number of elements in the network.

Fig. 1, type 3 shows a very common form of three-element two-terminal network.

Put

$$L\omega_0=\frac{1}{C\omega_0} \tag{4}$$

and

$$\frac{L\omega_0}{R}=Q; \tag{5}$$

$$\begin{aligned}Z&=\frac{1}{Cj\omega+\dfrac{1}{R+Lj\omega}}=\frac{R+Lj\omega}{1+Cj\omega(R+Lj\omega)}\\&=\frac{R+Lj\omega}{1-LC\omega^2+RCj\omega}=\frac{(R+Lj\omega)(1-LC\omega^2-RCj\omega)}{(1-LC\omega^2)^2+R^2C^2\omega^2}\\&=\frac{R}{(1-LC\omega^2)^2+R^2C^2\omega^2}\\&\quad+j\frac{L\omega(1-LC\omega^2)-R^2C\omega}{(1-LC\omega^2)^2+R^2C^2\omega^2}.\end{aligned} \tag{6}$$

The process of generalisation of this expression may be carried out in a number of ways by insertion of the parameters ω_0 and Q. It is evidently possible to eliminate any two of the element values, and to obtain resulting expressions which, when multiplied by the value of the remaining element, give the resultant resistance and reactance components of the impedance. Since, however, the purpose of a network of this kind is usually to obtain a high impedance at the resonant frequency, it is convenient to think of the condenser as a means of multiplying the reactance of the inductance by a calculable factor. For this reason the impedance is determined

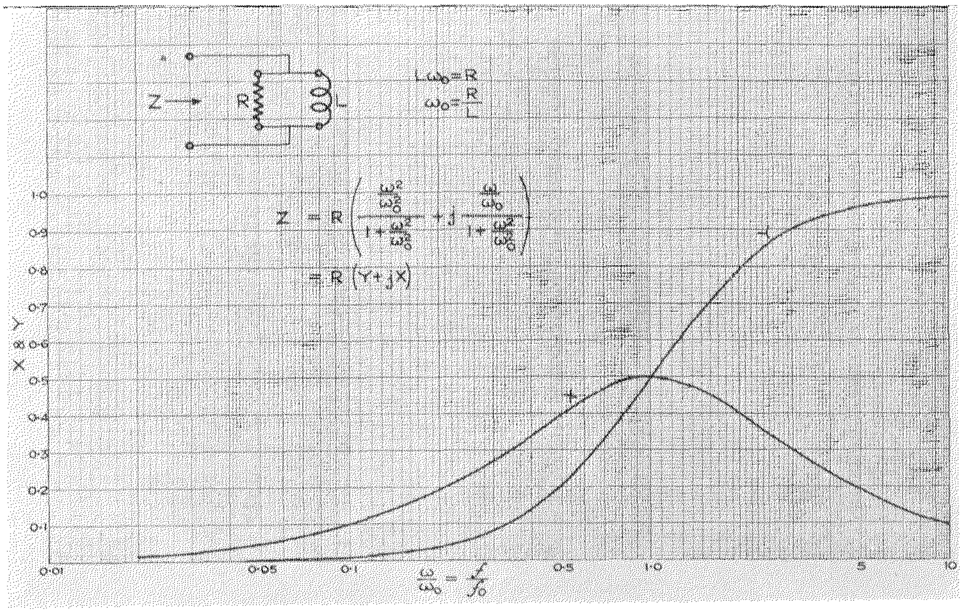

Fig. 2—Generalised Resistance and Reactance Curves for Network Shown.

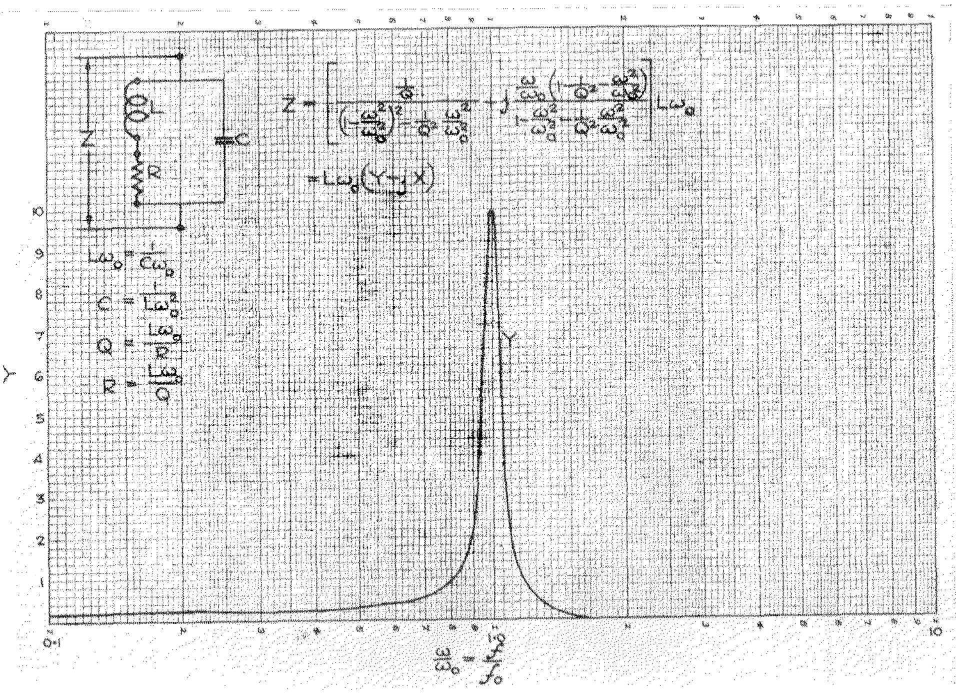

Fig. 3—Generalised Resistance Curve for Network Shown with Q = 10.

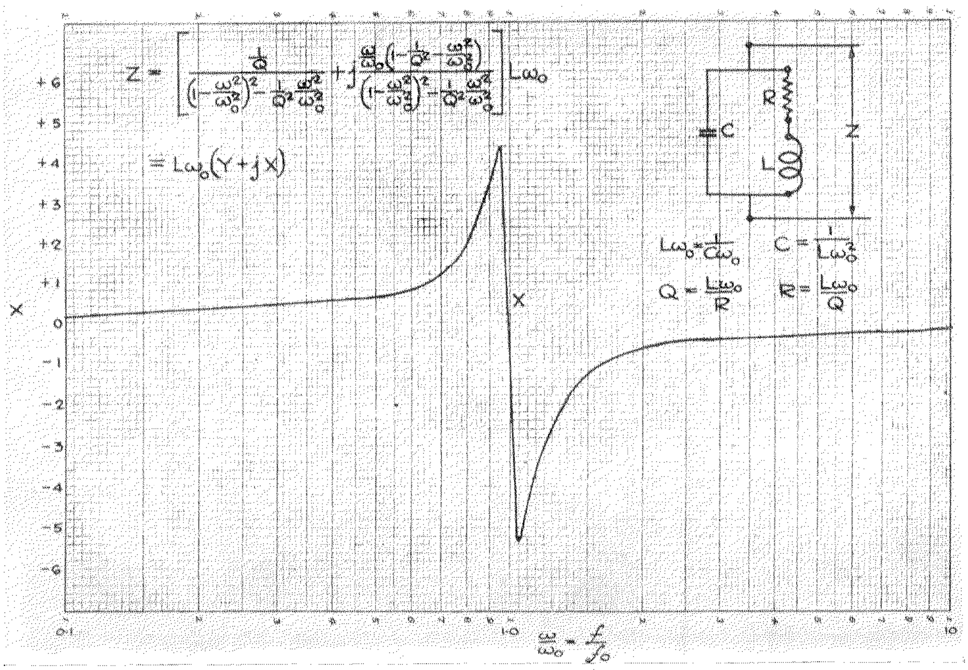

Fig. 4—Generalised Reactance Curve for Network Shown with Q = 10.

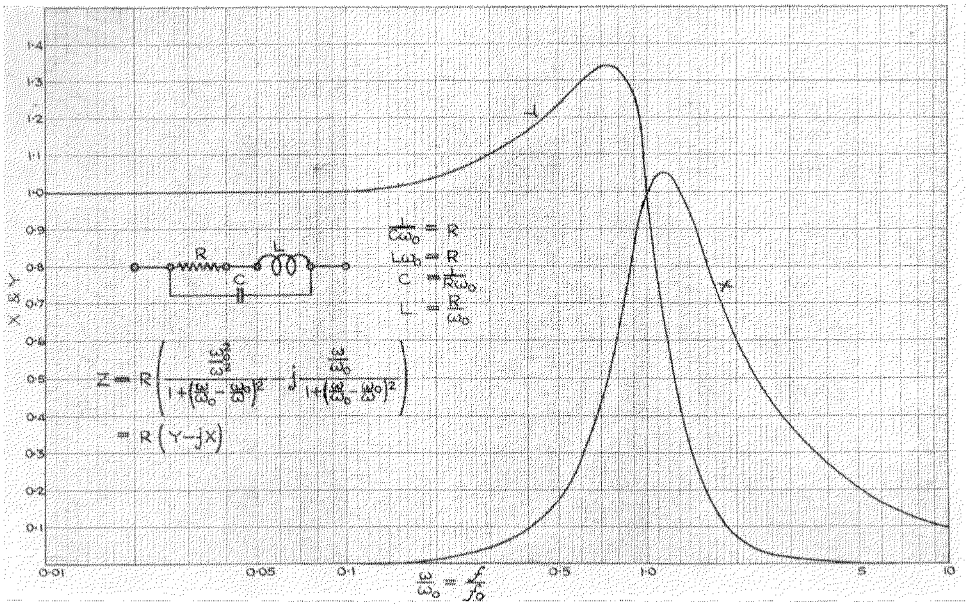

Fig. 5—Generalised Resistance and Reactance Curves for Network Shown.

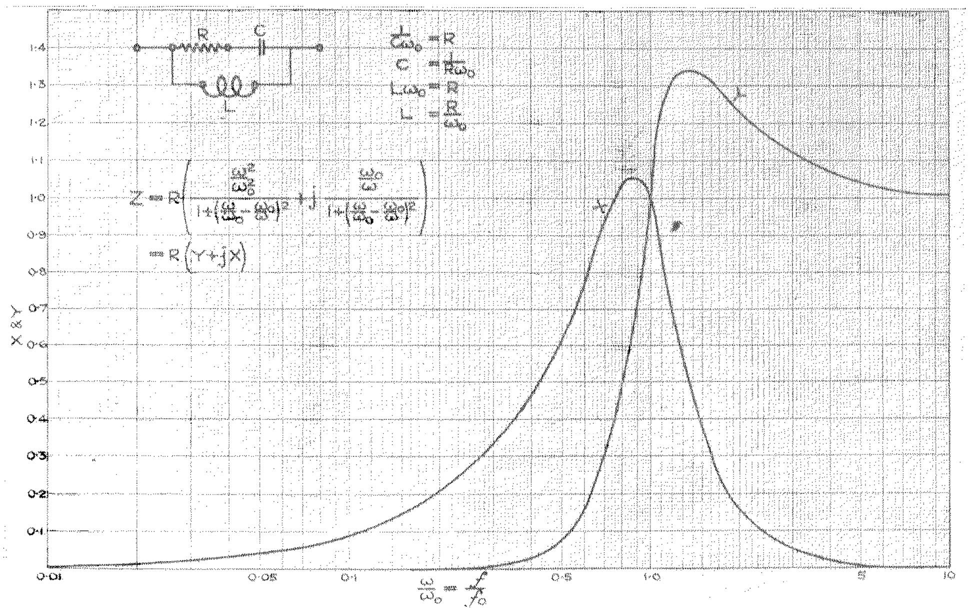

Fig. 6—Generalised Resistance and Reactance Curves for Network Shown.

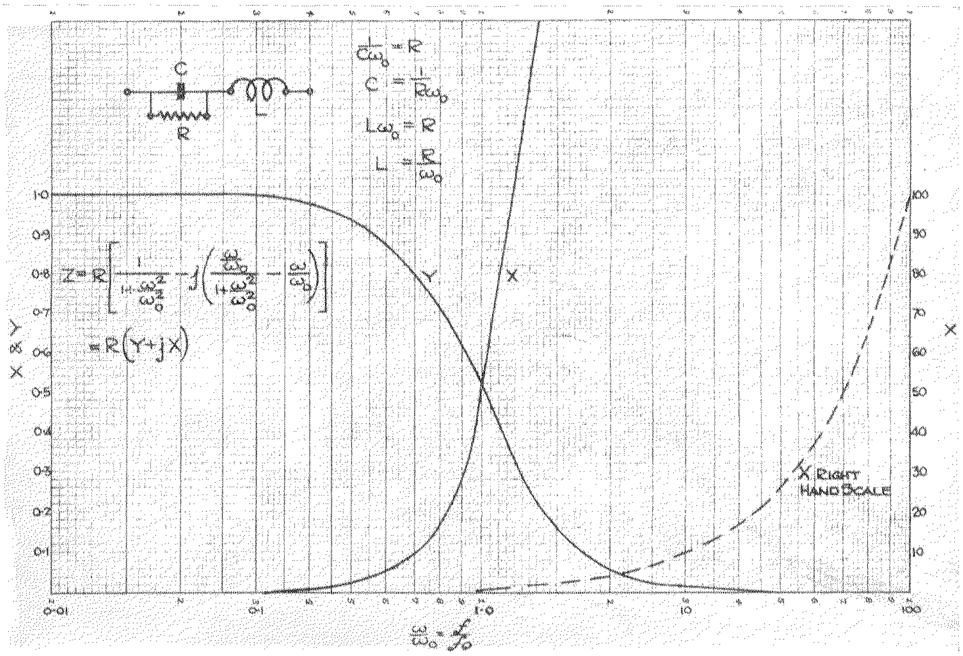

Fig. 7—Generalised Resistance and Reactance Curves for Network Shown.

as a function of $L\omega_0$, the reactance of L at resonance.

From (4) and (5) therefore are obtained

$$C=\frac{1}{L\omega_0^2} \tag{7}$$

and

$$R=\frac{L\omega_0}{Q}. \tag{8}$$

Substituting (7) and (8) in (6),

$$Z=\frac{\dfrac{L\omega_0}{Q}}{\left(1-\dfrac{\omega^2}{\omega_0^2}\right)^2+\dfrac{1}{Q^2}\dfrac{\omega^2}{\omega_0^2}}+j\frac{L\omega_0\dfrac{\omega}{\omega_0}\left(1-\dfrac{\omega^2}{\omega_0^2}-\dfrac{1}{Q^2}\right)}{\left(1-\dfrac{\omega^2}{\omega_0^2}\right)^2+\dfrac{1}{Q^2}\dfrac{\omega^2}{\omega_0^2}}$$

$$=L\omega_0\left[\frac{\dfrac{1}{Q}}{\left(1-\dfrac{\omega^2}{\omega_0^2}\right)^2+\dfrac{1}{Q^2}\dfrac{\omega^2}{\omega_0^2}}+j\frac{\dfrac{\omega}{\omega_0}\left(1-\dfrac{1}{Q^2}-\dfrac{\omega^2}{\omega_0^2}\right)}{\left(1-\dfrac{\omega^2}{\omega_0^2}\right)^2+\dfrac{1}{Q^2}\dfrac{\omega^2}{\omega_0^2}}\right]. \tag{9}$$

It may be noted in passing that when $\omega/\omega_0=1$, the real part of the impedance $=QL\omega_0$ and the imaginary part $=-L\omega_0$.

Evidently equation (9) represents a family of curves, the particular curve chosen being determined by the value of Q. Fig. 3 shows the curve for the resistance term inside the bracket and Fig. 4 the curve for the reactance term when $Q=10$.

To determine the absolute resistance and reactance curves, it is only necessary to fix L and C and so determine ω_0, or to fix L and ω_0 and so determine C.

Fig. 5 shows generalised curves for a type 3 network derived in terms of R instead of $L\omega_0$ for the case where $Q=1$, i.e., $L\omega_0=1/C\omega_0=R$.

Fig. 6 shows curves for a type 4 network (which is similar to type 3 with the resistance transferred from the inductance arm to the capacitance arm) for the case where $L\omega_0=1/C\omega_0=R$.

Comparing Figs. 5 and 6, it will be seen that one can be converted into the other by inverting one set of curves about the point $\omega/\omega_0=1$. This is equivalent to substituting ω_0/ω for ω/ω_0 on the frequency ratio scale. It should be noted that in Fig. 5 the reactance is always negative, and in Fig. 6 the reactance is always positive.

The generalised characteristics of networks (5) and (6) are shown respectively in Figs. 7 and 8 and, as might be expected, are mutual inverts about the point $\omega/\omega_0=1$.

There exists still another useful method of approach to the type 3 network, and that is when the capacitance represents an unwanted shunt capacitance, such as the grid cathode capacitance of a valve. The resistance is an existing circuit element in parallel with this capacitance, such as the anode resistance of the previous valve, and the inductance is added to effect partial neutralisation of the capacitance. The net effect of adding the inductance is to increase the impedance effective across the condenser terminals over a limited range of frequency.

Assume a value of neutralising inductance L is chosen such that $R=nL\omega_0=n/C\omega_0$ where $\omega_0=1/\sqrt{LC}$:

From equation (6) the reactive component of the resulting impedance

$$X=\frac{L\omega(1-LC\omega^2)-R^2C\omega}{(1-LC\omega^2)^2+R^2C^2\omega^2}.$$

Inserting $L=\dfrac{R}{n\omega_0}$ and $C=\dfrac{n}{R\omega_0}$,

$$X=\frac{\dfrac{R}{n}\dfrac{\omega}{\omega_0}\left(1-\dfrac{R}{n}\dfrac{n}{R}\dfrac{\omega^2}{\omega_0^2}\right)-R^2\dfrac{n}{R}\dfrac{\omega}{\omega_0}}{\left(1-\dfrac{\omega^2}{\omega_0^2}\right)^2+R^2\dfrac{n^2}{R^2\omega_0^2}\omega^2}$$

$$=R\left[\frac{\dfrac{\omega_0}{\omega}\left(\dfrac{1}{n}-n\right)-\dfrac{1}{n}\dfrac{\omega}{\omega_0}}{\left(\dfrac{\omega_0}{\omega}-\dfrac{\omega}{\omega_0}\right)^2+n^2}\right]. \tag{10}$$

Evidently, if the quantity $\dfrac{1}{n}-n$ is finite, the reactance assumes finite positive values at low frequencies. For certain purposes this may be regarded as undesirable and it is customary to make $n=1$, in which case

$$X=R\left[\frac{-\dfrac{\omega}{\omega_0}}{1+\left(\dfrac{\omega}{\omega_0}-\dfrac{\omega_0}{\omega}\right)^2}\right] \tag{11}$$

and

$$L=\frac{R}{\omega_0}=R\sqrt{LC}=R^2C. \tag{12}$$

The resistance and reactance characteristics of the resultant network are then given by Fig. 5.

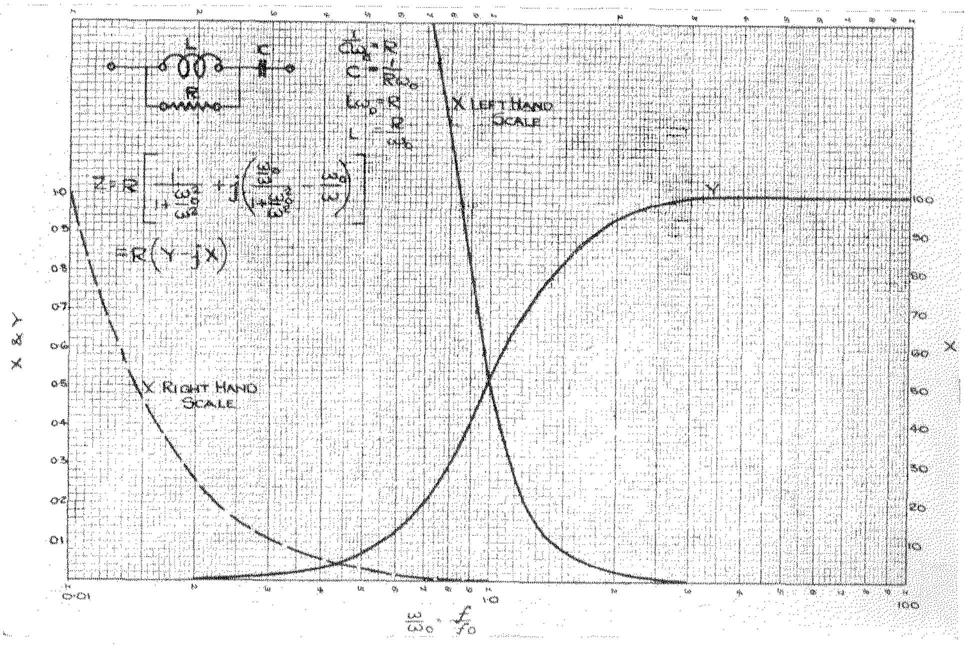

Fig. 8—Generalised Resistance and Reactance Curves for Network Shown.

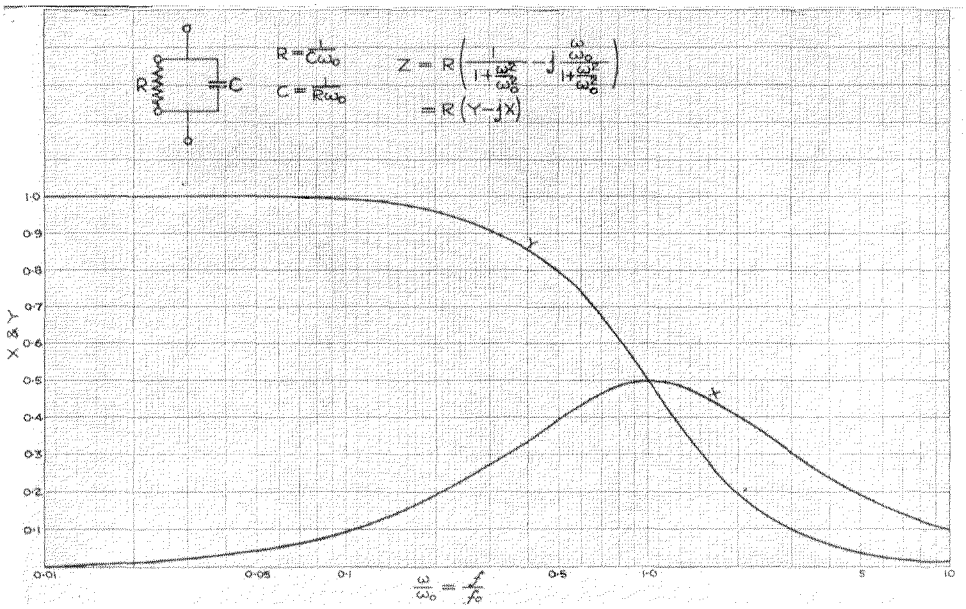

Fig. 9—Generalised Resistance and Reactance Curves for Network Shown.

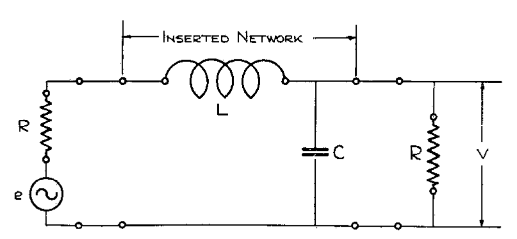

Fig. 10.

Fig. 9 shows the resistance and reactance characteristics of a type 2 network, representing the condition before the addition of the neutralising inductance. Some idea of the improvement realised by the addition of the neutralising inductance can be obtained by comparison of Figs. 5 and 9. For the purpose of comparison, these figures can be directly superposed with the $\omega/\omega_0 = 1$ points and the zeros of the X and Y scale coinciding. It will then be seen that the value of $Y+jX$ is appreciably larger over an interval of nearly two octaves when the inductance is added; the fall in impedance is delayed to a much higher frequency.

Four-Terminal Networks

The characteristics here considered are the usual transmission characteristics which determine the effect of the network in modifying electrical oscillations traversing it. Three characteristics will be defined.

(1) *The insertion loss proper* determines the change in the received energy and voltage consequent on the insertion of the network between two pieces of apparatus, a generator of alternating electromotive forces in a given range of frequency and a receiver. The generator and the receiver each have a definite impedance which, for many purposes, can be usefully considered to be a pure resistance, and often the impedances of generator and receiver are equal. When the generator is connected directly to the receiver, it delivers to the receiver energy and voltage of determined magnitude and phase. When the network is inserted, the received energy and voltage are changed in magnitude and phase. The amount of this change determines the insertion loss proper.

Evidently the insertion loss proper has two characteristics—a power ratio and a phase angle

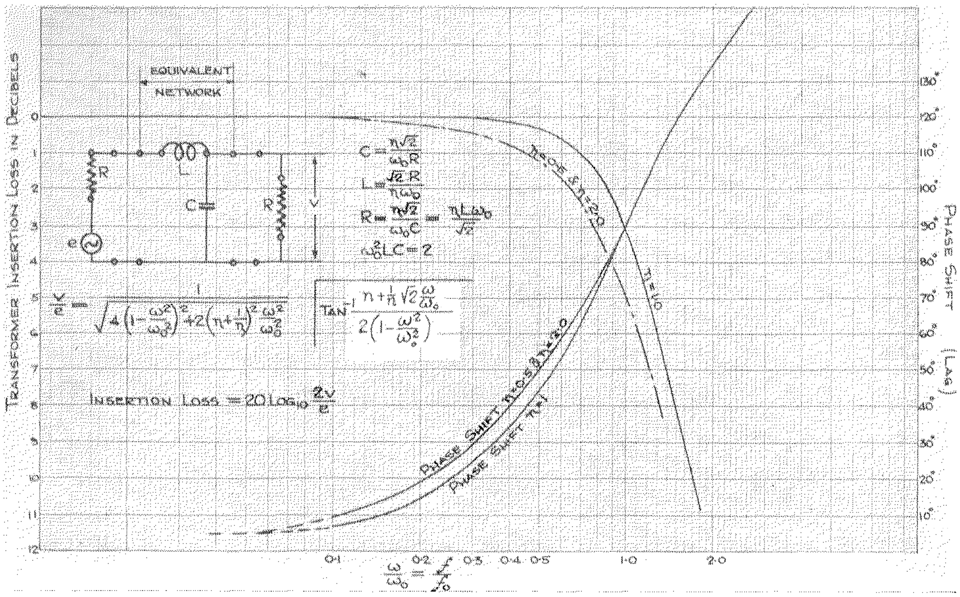

Fig. 11—High Frequency Insertion Loss and Phase Shift of Audio Frequency Transformers.

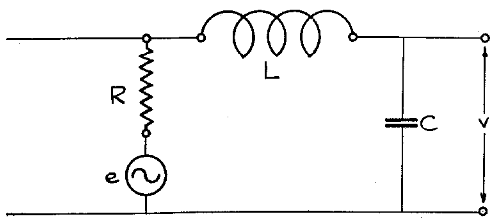

Fig. 12.

at each frequency. For simplicity, the term *insertion loss* will be used to refer to the power ratio and the term *insertion phase shift*, or simply phase shift, to refer to the angle.

The power ratio obviously may be expressed as the numerical ratio of P_1, the received power when the network is out of circuit, and P_2, the received power when the network is in circuit. More usually it is expressed in decibels or nepers. In the present case, decibels are used and the insertion loss is given by

$$L = 10 \log_{10} \frac{P_1}{P_2} \text{ decibels.}$$

If the generator impedance = the receiver impedance = a pure resistance, and if V_1 and V_2 are the received voltages corresponding respectively to P_1 and P_2, then

$$L = 20 \log_{10} \left| \frac{V_1}{V_2} \right| \text{ decibels.}$$

The vertical bars each side of the fraction $\frac{V_1}{V_2}$ indicate that the magnitude of the voltage vectors is to be taken.

(2) *The voltage transfer constant* is the vector ratio between the vectors, respectively, describing the input voltage applied to the network and the voltage observed across the output terminal of the network, defined by $\frac{\text{output voltage}}{\text{input voltage}}$. It is most conveniently determined by two curves plotted against frequency, one of the magnitude of the voltage transfer constant, and the other of the angle of the voltage transfer constant.

(3) *The voltage transfer loss* is probably a new term and is expressed as the number of decibels which correspond to A, the magnitude of the voltage transfer constant.

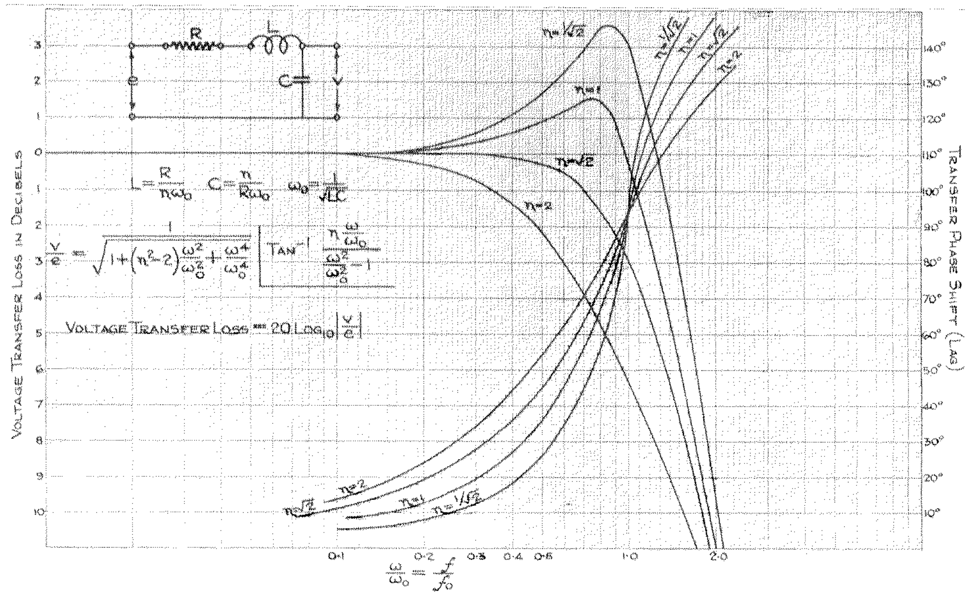

Fig. 13—High Frequency Response and Phase Shift for Audio Frequency Transformers Working into Open Circuit.

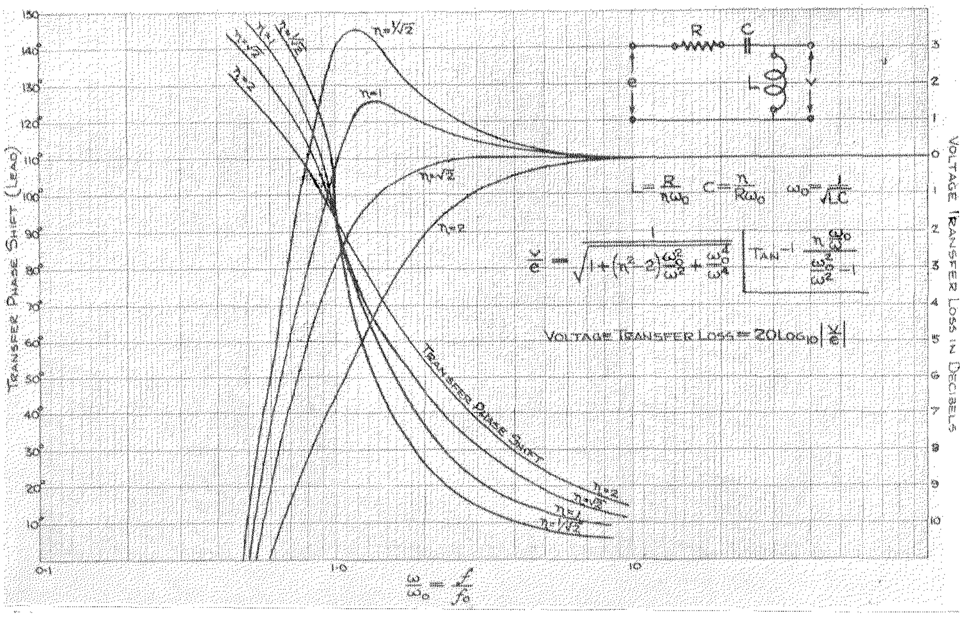

Fig. 14—Transfer Loss and Phase Shift for Network Shown.

The voltage transfer loss

$$L_T = 20 \log_{10} A.$$

The use of this term appears to be logical and is justified by its convenience. In this case the phase shift may be defined as the transfer phase shift, but no ambiguity results if the term phase shift is used alone.

It is difficult to lay down rigid rules which determine when each type of characteristic should be used to describe the performance of a network. When the network operates between finite impedances there is no choice: the insertion loss proper must be used, described by the insertion loss and the insertion phase shift as defined above. When the network can be regarded as operating between a generator of zero impedance and open circuit (infinite receiving impedance) the convention adopted is largely a matter of personal preference. Since the received power is zero, it is rather difficult to modify suitably the definition of the insertion loss to describe the network characteristics under this condition, and the use of the voltage transfer constant or the voltage transfer loss is preferable. The voltage transfer constant is evidently used if voltage ratios are easier to handle; and the voltage transfer loss, if losses in decibels are required. This case arises in considering coupling circuits between valves when the anode impedance of the first valve and the grid-filament capacity of the second valve are treated as part of the network and the grid-filament conductance of the second valve is low enough to be considered zero.

Example of Network Treated by Use of Insertion Loss

Fig. 10 shows the equivalent circuit for the high frequency resonance of a communication transformer working between image impedances. The method of deriving this circuit has been described in *Electrical Communication.*[1] The voltage

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[1] "Transformers as Band Pass Filters," by E. K. Sandeman, *Electrical Communication*, April, 1929.

$$V=\frac{\dfrac{R}{1+j\omega CR}}{R+j\omega L+\dfrac{R}{1+j\omega CR}}\,e$$

$$=\frac{e}{\sqrt{(2-\omega^2CL)^2+\left(\omega CR+\dfrac{\omega L}{R}\right)^2}}\Big/\underline{\text{Tan}^{-1}\frac{\omega CR^2+\omega L}{\omega^2RLC-2R}}. \qquad (13)$$

Put $\omega_0^2=\dfrac{2}{LC}$ and $\dfrac{\omega_0CR}{\sqrt{2}}=\dfrac{\sqrt{2}R}{\omega_0L}=n$;

then

$$C=\frac{n\sqrt{2}}{\omega_0R} \quad\text{and}\quad L=\frac{R\sqrt{2}}{n\omega_0}. \qquad (14)$$

Substituting (14) in (13),

$$\frac{V}{e}=\frac{1}{\sqrt{4\left(1-\dfrac{\omega^2}{\omega_0^2}\right)^2+2\left(n+\dfrac{1}{n}\right)^2\dfrac{\omega^2}{\omega_0^2}}}\ \overline{\Big\backslash\ \text{Tan}^{-1}\frac{\left(n+\dfrac{1}{n}\right)\sqrt{2}\dfrac{\omega}{\omega_0}}{2\left(1-\dfrac{\omega^2}{\omega_0^2}\right)}} \qquad (15)$$

$$=A\overline{\backslash\phi}.$$

The negative value of the angle makes the sense indeterminate from the analysis, but it is evident that the angle always represents a lag.

Since, in the absence of the network, $V=\frac{1}{2}e$, the insertion loss proper is expressed by the ratio $2A\overline{\backslash\phi}$ and the insertion loss is expressed in decibels by

$$L=20\log_{10}2A.$$

The insertion loss and the insertion phase shift of the network of Fig. 10 are shown in Fig. 11 for $n=0.5$, 1.0, and 2. It is evident that an ideal design of transformer results if n is made equal to unity.

Example of Network Treated by Use of a Voltage Transfer Loss

Fig. 12 shows the equivalent circuit for the high frequency resonance of a communication transformer working into open circuit. The method of deriving this circuit will be clear by reference to the above mentioned article.

The voltage transfer constant

$$\frac{V}{e}=\frac{1}{\sqrt{1+(n^2-2)\dfrac{\omega^2}{\omega_0^2}+\dfrac{\omega^4}{\omega_0^4}}}\ \overline{\Big\backslash\ \text{Tan}^{-1}\frac{n\dfrac{\omega}{\omega_0}}{1-\dfrac{\omega^2}{\omega_0^2}}}$$

$$=A\overline{\backslash\phi},$$

where

$$n=RC\omega_0=\frac{R}{L\omega_0},$$

$$\omega_0=\frac{1}{\sqrt{LC}},\qquad C=\frac{n}{\omega_0R}\quad\text{and}\quad L=\frac{R}{n\omega_0}.$$

The voltage transfer loss is given by $L_T=20\log_{10}\left|\dfrac{V}{e}\right|=20\log_{10}A$.

The voltage transfer loss and the phase shift of the network of Fig. 12 are shown in Fig. 13 for values of $n=\dfrac{1}{\sqrt{2}}$, 1, $\sqrt{2}$, and 2.

Figs. 14–18 show the characteristics of five other networks, in forms appropriate to the work to which they were originally applicable. They also show the method of deriving the parameters and the generalised formulae for the insertion loss, voltage transfer constant, voltage transfer loss, whichever is relevant, and for the phase shift. For purposes of practical application each figure is complete in itself, containing all the necessary data to enable the absolute frequency scale for any particular embodiment to be aligned with the generalised scale of $\dfrac{\omega}{\omega_0}=\dfrac{f}{f_0}$. There are, however, a few points which appear worthy of comment.

An important point to notice is the principle of inversion by which the characteristics of one network can be derived from another by inversion about the axis $\dfrac{\omega}{\omega_0}=1$. The formula for the second network is derived by substituting $\dfrac{\omega_0}{\omega}$ for $\dfrac{\omega}{\omega_0}$ in the formula for the first network, and by changing the sign of the reactance or phase shift.

The necessary and sufficient conditions which make such an inversion possible are: firstly, that the second network is derived from the first by changing every inductance into a capacity and

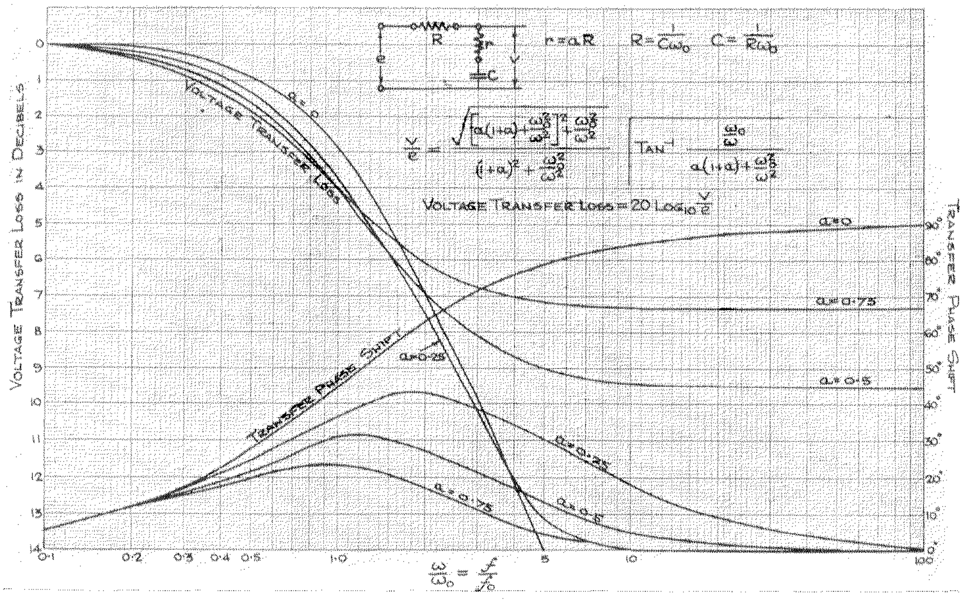

Fig. 15—Transfer Loss and Phase Shift for Network Shown.

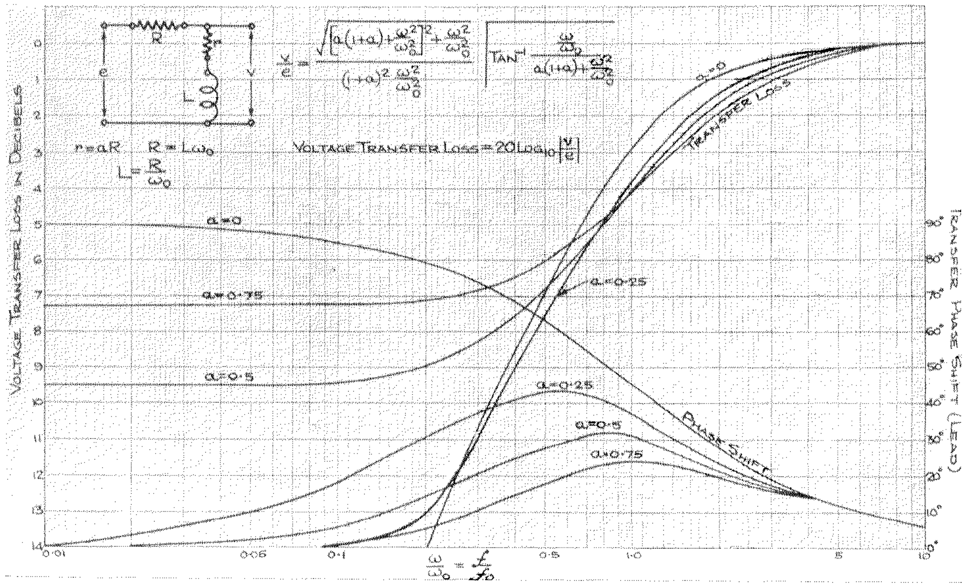

Fig. 16—Transfer Loss and Phase Shift for Network Shown.

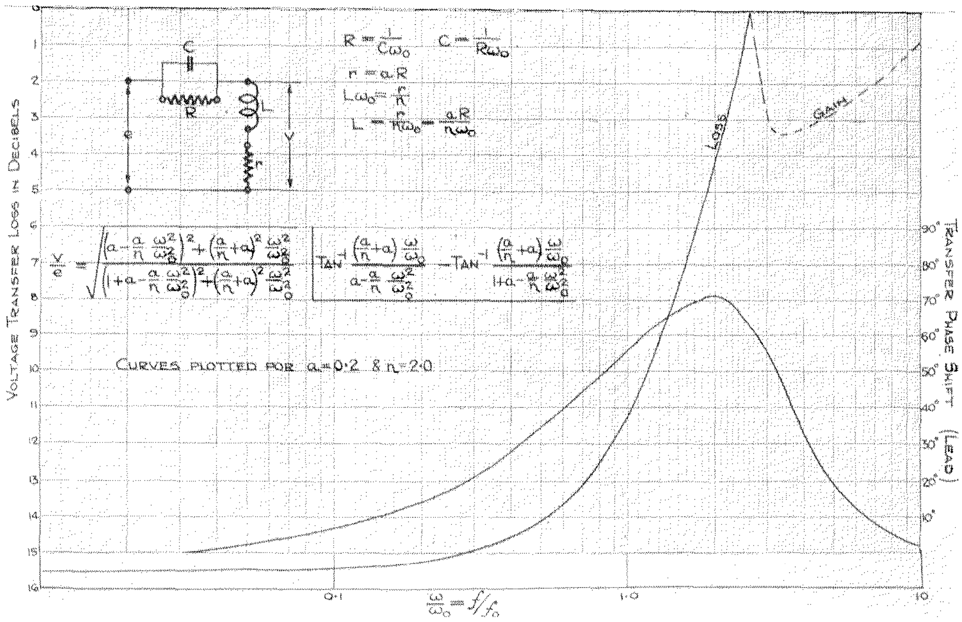

Fig. 17—Transfer Loss and Phase Shift for Network Shown.

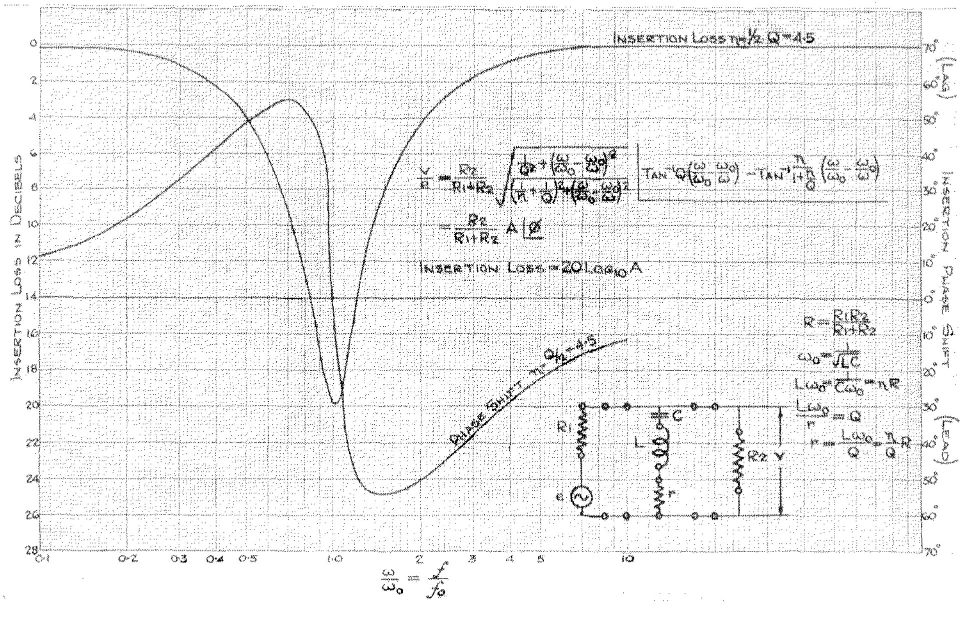

Fig. 18—High Frequency Insertion Loss and Phase Shift for Audio Frequency Transformers.

vice versa; secondly, that the controlling parameters relating ω_0 and the various elements of the network shall be the same. If, for instance, a controlling parameter in the first network is given by $L\omega_0 = aR$, the corresponding parameter in the second network is given by $\frac{1}{C\omega_0} = a'R$, where C replaces L, and a' must equal a for the condition of inversion to hold. As the labour of deriving the formulae and evaluating them is very considerable in the more complicated cases, the value of this principle will be easily appreciated. Examples of such inversion are: Figs. 5 and 6; Figs. 2 and 9; Figs. 13 and 14; and Figs. 15 and 16. In each instance calculation was made for one case only and the formula and characteristics for the inverted network derived by applying the principle of inversion. Care must be observed in applying this principle to see that appropriate changes are made in the signs of the reactance and phase shifts.

It will be noted that in certain cases, in order to save space, positive and negative reactances have been plotted in the same direction and distinguished by + and − signs. For the same reason, in Fig. 17, the part of the response curve representing a gain has been inverted about the axis of zero loss.

In certain cases, for instance, where valves can be used as separating elements, it is possible to combine the curves of several networks by adding or subtracting ordinates directly. Thus, the preliminary investigation can be made entirely in terms of the generalised curves, sliding them over one another until a composite curve of the required form is obtained. The values of the circuit elements of the component networks follow as soon as the position of the composite curve (and therefore of the component curves) in the frequency gamut is fixed. It is found in practice that the possession of a series of generalised curves such as the above enables studies, which would otherwise be quite impracticable, to be made comparatively without effort.

The collection of curves given is necessarily limited since the time involved in constructing them is appreciable. The author hopes to publish a more extensive list at some future date and would be grateful to hear from colleges or private individuals who would be interested in collaborating.

The Community Aerial System of Broadcast Distribution

By C. W. EARP AND S. HILL
Kolster-Brandes, Limited, Sidcup, England

The Problem

RADIO reception in a modern flat-colony presents two special problems: (1) providing the users with efficient non-interfering aerials which must, of course, not be unsightly; and (2) reducing the static interference which is always considerable because of the many electrical services provided.

The solution of these problems demands a co-operative effort which the tenants naturally tend to relegate to the proprietors of their establishment. For this reason, radio is coming to be regarded as a fundamental service, which a tenant expects along with water, electricity, or the telephone, and there is a rising demand among builders and architects for a complete system whereby a flexible, noise-free radio service may be "laid on" to each apartment. The Community Aerial System was developed for such a service.

In studying the community aerial system, we may conveniently divide it into two parts: the provision of an efficient aerial system, generally on the roof of the building, with a radio frequency transmission line to bring signals to the main distributing point; and a system of aperiodic amplification and distribution to convey the signals to the consumer.

The division is historically convenient since the first part of the problem was solved first by means of the "Rejectostat System," while the second part is a more modern development. Inasmuch as the rejectostat system is already widely known, the main purpose of this article is to expound the second part of the problem.

The Rejectostat System

In this system, which has application to individual as well as to community installations, an aerial is erected outside the noise cloud, which is generally associated with the building itself—partly because the interfering sources are usually indoors, and partly because house wiring radiates a disturbing field. A low impedance shielded transmission line with suitable impedance changing transformers at each end, carries the signals to the receiver which is, itself, preferably shielded with special care. Such installations have been highly successful in reducing local noise and have certain obvious auxiliary advantages; for example, since the aerial may be remote, it can generally be made better than one whose position is fixed near to a particular set, and the resulting improvement usually more than compensates for transmission losses. Better protection against lightning discharges can also be achieved and the choice of location of the receiver is wider.

The Amplifier

One good aerial, well removed from the local noise cloud, can nearly always be erected on the roof of a block of flats, and collects enough energy to supply several radio receivers. To supply energy to all the residents, however, it is necessary to amplify the signal currents from the aerial aperiodically, and deliver them to a low impedance line.

Figs. 1-*A* and 1-*B* show a ten-valve amplifier manufactured by Kolster-Brandes, Ltd., suitable for supplying about one hundred receivers. The schematic is shown in Fig. 2. There are two Brimar R.3 rectifiers (two are provided for greater reliability) and ten Brimar 9D2 pentodes forming a single stage. A filter is included to suppress audio frequencies and very long wave telegraph signals which, because of the impracticability of maintaining the sheath at earth potential throughout its length, are often picked up on the aerial transmission line and may modulate the wanted signals at telegraph frequencies. Wave traps are also sometimes included to reduce the signals from powerful local stations.

Principle of Operation

The chief technical problem of securing efficient vacuum tube amplification of a wide band of frequencies from a low impedance source is the design of a good step-up transformer from the line to the high grid impedance of the valves, and a similar step-down transformer from anode to line impedance.

The high input step-up is necessary not only for efficiency but also to minimise the effect of valve anode noise. It is shown in the Appendix that valves of normal design must work from impedances of not less than 100,000 ohms. It was found impracticable to design sufficiently good transformers to cover the whole range, and the arrangement of Fig. 3 was accordingly adopted. As the technique of transformer design is improving, it is possible that other methods of amplification will become practicable, and are indeed now being explored. However, it will be seen that the method here described has several special advantages for community aerial work.

The line impedance of 100 ohms is matched at frequencies f_1, f_2, f_3, etc., by series tuned circuits of 100 ohms impedance composed of L_1C_1, L_2C_2, L_3C_3, respectively. Frequencies f_1, $f_2 \cdots f_n$ are chosen at regular intervals, which are just small enough to ensure good absorption of energy from the line at all frequencies within the band it is desired to pass. It will be seen that the circuit L_nC_n will absorb practically no energy from the line except at the desired frequency, for its impedance rises rapidly on either side of resonance.

The various outputs OP_1, OP_2, etc., now have very high impedances at resonance, of the order of 500,000 ohms, being closed by a parallel tuned circuit L_1C_1, L_2C_2, etc.

Instead of the orthodox transformer, we have therefore a single low-impedance input on one side, and a number of pairs of output terminals. Signal energy entering at the "primary" terminals is selected in a number of frequency bands and stepped up in voltage and impedance to various output terminals. These outputs OP_1, OP_2, etc., are ideally suitable for the connection of valve grids.

A similar device is used for the transformation of signal energy from numerous high-impedance sources (the anodes of the amplifiers) to a 100 ohm output line. In this case, of course, the valve anode impedances are strapped across the various circuits, and modified circuit constants are necessary for exact matching.

In practice it is found desirable to "stagger" grid and plate resonances so that variation of gain over the band may be minimised. The resultant characteristic is shown in Fig. 4.

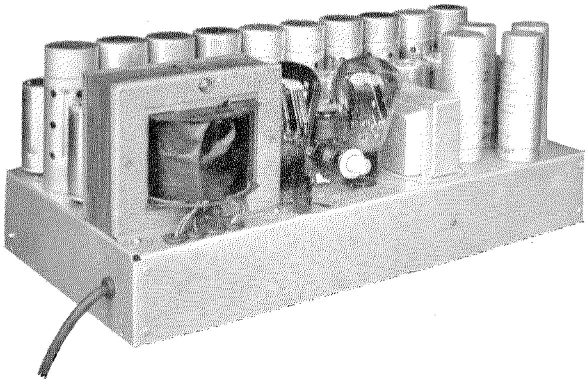

Fig. 1-A—10 Valve Kolster-Brandes Amplifier Chassis.

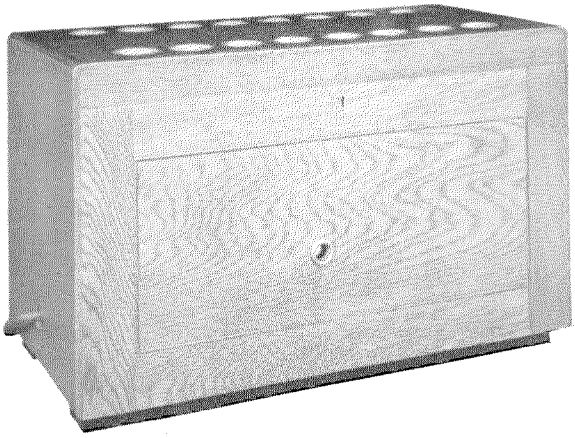

Fig. 1-B—10 Valve Kolster-Brandes Amplifier.

Design for Frequency Coverage Using the Minimum Number of Valves

If a signal V_g is applied to the grid of a valve of mutual conductance $\frac{\mu}{Z_a} = g\ mA/\text{volt}$, and if a tuned circuit of three parallel elements, L, C, R be inserted in its anode circuit, the frequency band width for which the output voltage falls by a factor p is easily shown to be

$$f_1 - f_2 = \frac{(R+Z_a)\sqrt{p^2-1}}{2\pi RCZ_a}$$

and the stage gain is similarly written

$$\frac{\mu R}{R+Z_a}.$$

The product of band width and stage gain then reduces to

$$\frac{g\sqrt{p^2-1}}{2000\pi C}.$$

Here C must include the inherent valve capacity C_p and cannot fall below this value. The expression $\frac{g}{2000\pi C}$ may be defined as the amplifier performance factor. It depends only on the excellence of the valve used and the capacity in the tuned circuit, reaching a maximum of

$$\frac{g}{2000\pi C_p} \quad \text{when} \quad C=C_p.$$

This analysis suggests that the best performance would be secured by making each coil resonate with the valve capacity. For convenience of adjustment, trimmers are provided, but they are made as small as possible. The formulae further indicate that the best possible "amplification coverage" for a single-stage amplifier is approached.

The single-stage amplifier is particularly desirable in this case, since each valve is able to supply useful output power to the line, and no single valve must handle a large peak voltage.

It is interesting to note incidentally that, since the development of this amplifier, the technique of transformer design has advanced considerably and, also, the principle of "negative feedback" has been used extensively to improve the power-handling capabilities of a single valve without distortion. It is probable that, by eliminating overload problems, a more efficient amplifier will be obtained by using fewer valves in cascade formation.

Advantages of the Amplifier Described

The following advantages may be briefly enumerated:

(1) *Amplification Coverage.* The performance factor of each valve is very near its theoretical maximum, and good coverage is therefore obtained with valves operated in parallel formation.

(2) *Efficiency.* Every valve is used to deliver power to the line, and each valve may be fully loaded. The output is correctly matched to the line at all frequencies.

(3) *Reliability.* The failure of any one valve does not put the whole system out of action, but only causes a reduction in output over a small frequency band.

(4) *Cross Modulation.* Cross modulation is no more evident than in an ordinary commercial receiver. If noticeable, it may usually be removed by means of the wave traps provided, or by ensuring that the offending local lies in the trough between two peaks.

(5) *Absence of Phantom Signals.* Such signals, due to difference and summation frequencies, are not produced.

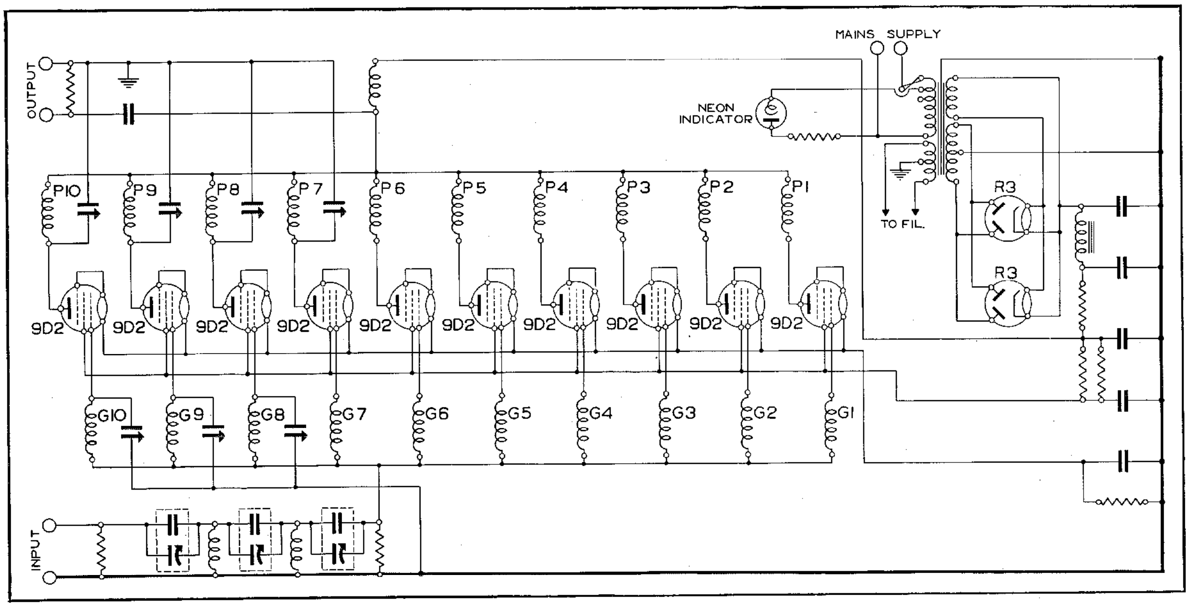

Fig. 2—Circuit Schematic of 10 Valve Kolster-Brandes Amplifier.

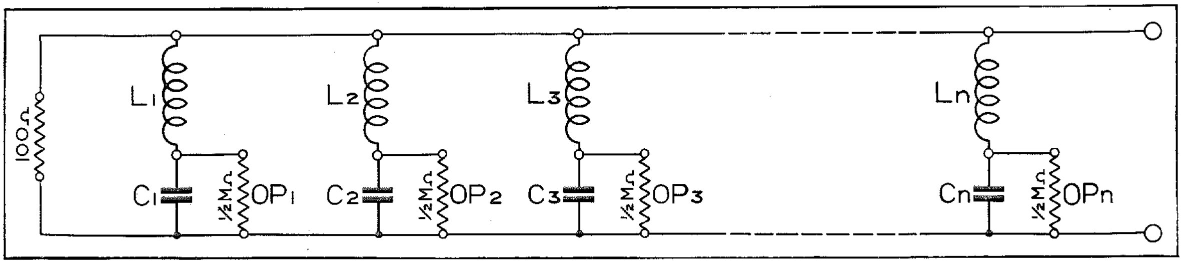

Fig. 3—Schematic Showing the Principle of the Rejectostat Amplifier.

(6) *Overloading.* Slight overloading of the valves is not troublesome since the tuned circuits in the anodes filter away distortion products.

(7) *Absence of Circuit Noise.* The efficient signal step-up from line to grids ensures a good signal/noise ratio. As the signal step-up from aerial to grid is considerably better than in the average commercial broadcast receiver, a better performance, in general, can be expected.

(8) *Absence of Amplifier Schrott Noise.* The use of H.F. pentodes of high slope and low anode current reduces Schrott noise to a minimum. The high grid impedances ensure that anode noise of the valve is small compared with circuit noise.

(9) *Flexibility.* Since the whole spectrum is naturally divided into frequency bands (one for each grid circuit and one for each anode circuit), adjustments can readily be made to improve any individual band, which may be found too weak, at the expense of other bands which may be too strong.

(10) *Negligible Phase Distortion.* Phase distortion can be made negligible over the whole frequency range. It is interesting to note that the human ear functions on the same principle of contiguous resonance bands.

(11) *Additional Grid Bias.* If necessary, a diode detector could be associated with each anode circuit and arranged to give an additional bias to the grid circuits whenever a signal exceeded a predetermined level. This elaboration has not yet been applied in practice.

(12) *Low Cost.* As the apparatus is made entirely of standard broadcast receiver components, it can be manufactured economically. Standard valves are also used, so that no special stock of spares need be kept.

(13) *Simplicity and Ease of Maintenance.* The amplifier contains no delicately balanced circuits and requires no accurate adjustments needing skilled attention. Given a stable trimmer design, there is nothing to get out of adjustment after installation. The amplifier may be left operating continuously, with a time switch to prevent tenants using the system at inconvenient times, i.e., in the middle of the night. Since the anode voltages used are those of an ordinary receiver, no special protection devices are needed. A monthly inspection is all the attention the amplifier requires.

(14) *Use as R.F. Repeater.* In some cases, an unusually long transmission line is necessary. For example, one radio rediffusion company proposes to erect a good aerial system several miles removed from a rediffusion centre. It is probable that repeater stations would be necessary on such a line.

"Rejectostat" amplifiers can be arranged in series to give any desired overall frequency-gain characteristic, inasmuch as frequency characteristics can be adjusted according to line loss.

Amplifiers provided with selective automatic gain control, as described in (11) above, would automatically adjust the signal levels at all points on the line.

(15) *Adaptation to Short Waves.* The amplifier may quickly be modified for the reception of short wave signals. This type of amplifier would be particularly adaptable since the various small frequency bands used for short wave broadcast transmission could be dealt with by a single valve.

(16) *Television Amplifier.* It has been shown earlier that the maximum amplifying capabilities of one particular valve are definitely limited by electrode capacity, at whatever frequency it may operate. The construction of wide-band television amplifiers has given considerable difficulty due to this fact. This type of amplifier, however, can be designed to cover any band without reducing

valve stage-gain to a point where Schrott noise becomes limiting.

The Problem of Distribution

The transmission of signals from the amplifier to the consumer may be studied by means of the classical telephone equation which, in its differential form, may be written

$$\frac{dv}{dx} = -ZI; \qquad \frac{dI}{dx} = -YV;$$

or, in its integrated form,

$$V = V_0 \cosh P - I_0 Z_k \sinh P,$$

$$I = I_0 \cosh P - \frac{V_0}{Z_k} \sinh P.$$

The only difference between radio frequency and telephone frequency transmission, lies in the different relative importance of the numerical factors. Practical cables may have constants of the following order at 1,000 kc:

$R = 400$ ohms/mile,
$L\omega = 6000$ ohms/mile,
$G = 0.04$ mhos/mile,
$C\omega = 0.6$ mhos/mile,
$Z_k = 100$ ohms.
Velocity of propagation 100,000 miles/sec.
Attenuation 35 db/mile.

In these circumstances, i.e., when the power factors are low, the attenuation is governed mainly by the resistance and leakance, R and G, while L and C mainly determine the characteristic impedance Z_k.

The input impedance of a short feeder branched from the main transmission line is capacitative. When, therefore, receivers are connected across the line, two loading effects are introduced, viz., (a) a capacitative loading due to the feeder, and (b) a resistive loading due to the pads which must be inserted before each receiver to prevent accidental line shorts, and reduce inter-receiver reaction. If these loads are not sufficient to affect the above conditions of low power factor, they may be treated separately, the capacities affecting the line impedances, and the resistances the attenuation. The resistive loads are most simply treated as if the spacing were infinite, this assumption being included in the statement that they do not greatly affect the characteristic impedance. If there be n such loads, each of leakance g mhos across a 100 ohm line, the bridging loss is $20\, n \log_{10} (1+50g)$ db.

The capacity loads are rather more difficult to treat. The simplest method is to split the line into a series of equivalent π pads whose shunt elements are each $Z_k \coth \frac{Px}{2}$ and whose series elements are $Z_k \sinh Px$, where x is the average

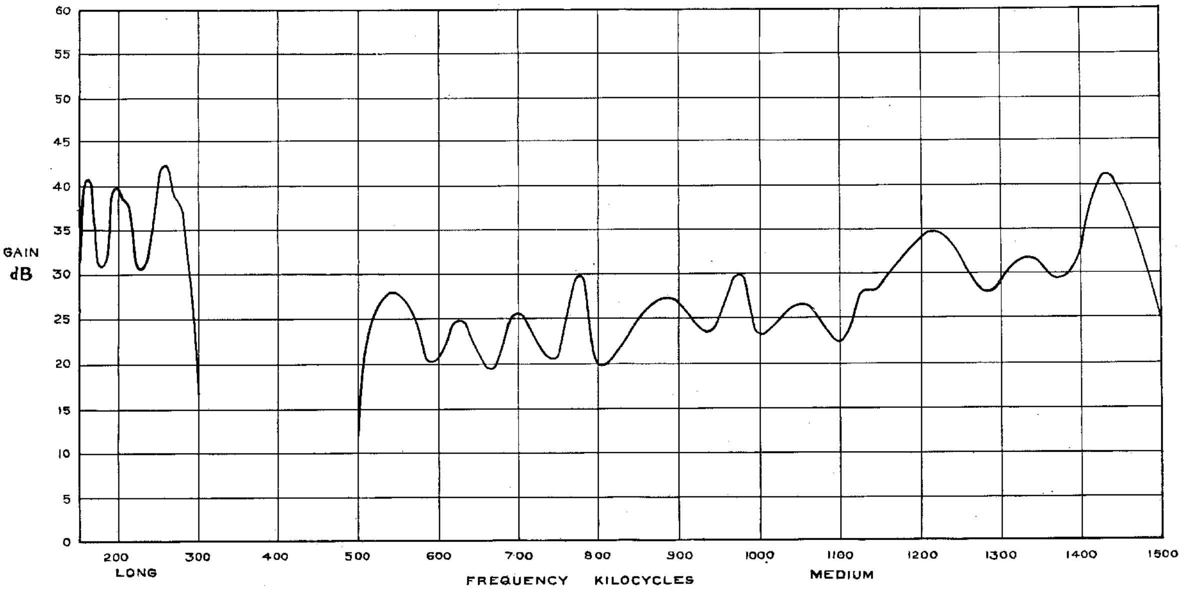

Fig. 4—Amplifier Characteristics.

length between loading points. When the attenuation is small, the approximate forms $-jZ_k \cot \theta$ and $jZ_k \sin 2\theta$ may be used, where θ is the length x expressed as a fraction of the wavelength along the cable. Since the velocity of propagation is of the order of one-half the velocity of light, the wavelength along the cable is one-half the free-space wavelength. To each of the shunt elements of the equivalent pads so calculated, may be added the appropriate capacity loading, and the new π pads so formed may be treated as recurrent structures using the theory developed for wave-filters. Thus if Z_1 and Z_2 be the total series and shunt impedance per full section, the iterative impedance, which is also the new characteristic line impedance, becomes

$$\sqrt{\frac{Z_1 Z_2}{1+\frac{Z_1}{4Z_2}}}.$$

The treatment is limited to small loads, but it is essential for correct operation that the loads be kept small, or serious standing waves will occur. In practice, therefore, no taps are permitted longer than one-sixteenth of a wavelength, and the characteristic impedance must not be changed more than 25% by feeder lines. It is therefore usually desirable to avoid taps by looping in each receiver.

Receiver pads usually consist of two resistances (one in each leg) built out between the line and the receiver. The minimum value of these resistances has been found in practice to be 500 ohms and is generally rather higher.

There are usually four sources of loss in the transmission system:

(*a*) The transformer loss. If more than one line be fed from one amplifier, or if the characteristic impedance is much below 100 ohms, a step-down transformer must be included between the amplifier and the lines. The voltage loss of this transformer is immediately calculable from its step-down ratio.

(*b*) The pad loss. By inserting various resistances between a 100 ohm source and the receiver, curves of pad loss may be prepared for various types of receiver.

(*c*) Line loss. The shielded, single core, rubber covered cable usually used has a loss varying from 7 db per mile at 150 kc to 40 db per mile at 1,500 kc. The characteristic impedance is roughly 100 ohms over this range. The increasing loss with increasing frequency makes it desirable so to tune the amplifier that it has a rising frequency characteristic.

(*d*) Bridging loss. This has already been considered. It is occasionally worth while to taper this loss so as to increase the signal at the end receivers at the expense of those near the beginning. Generally, however, it is preferable to divide the line into two sections fed from the same or separate amplifiers.

In designing a distribution scheme, the losses detailed above must be calculated for various possible dispositions of cables and amplifiers, and the most economical scheme selected. No universal rule can be laid down, and the designer has to be guided by past experience of other installations. Two amplifiers are at present available, viz., an eight valve and a ten valve amplifier. In an average installation, the eight valve amplifier will operate 50 and the ten valve amplifier 100 receivers. If necessary, two amplifiers may be connected in cascade, provided precautions are taken against overloading the second one, or the transmission line may be split into several short lengths, each connected to a different amplifier.

In designing the distribution system, it is necessary to assume an average receiver. Where a tenant possesses a receiver of unsuitable impedance, a matching transformer may have to be inserted before allowing him to connect the set to the line. Similar transformers are often necessary to maintain a balance to ground, which is essential in very noisy locations to minimize noise.

APPENDIX

Valve Noise and Circuit Noise Considerations

V_s = "Schrott" noise, or anode noise developed across the anode load impedance

V_j = "Johnson" or circuit noise developed in the grid circuit

I_a = Anode current

e = Charge on an electron

μ = amplification factor of the valve

R_2 = Impedance of load in anode circuit
ρ = Internal impedance of valve
df = Element of frequency band
R_1 = Grid circuit impedance
T = Absolute temperature of grid circuit
k = Boltzman's constant
V_{jp} = Noise voltage in the anode circuit, due to "Johnson" noise on the grid

Assuming the two following formulae:*

$$(V_s)^2 = 2I_a e \frac{(\rho R_2)^2}{(\rho + R_2)^2} df,$$

and

$$(V_j)^2 = 4R_1 kT df,$$

we have

$$(V_{jp})^2 = 4R_1 kT df \frac{(\mu R_2)^2}{(\rho + R_2)^2},$$

$$\frac{(V_{jp})^2}{(V_s)^2} = \frac{2kTR_1\mu^2}{I_a e \rho^2}.$$

If $k = 1.37 \times 10^{-23}$ joule per degree centigrade (Boltzman's constant),

$T = 290°$ abs.,

$e = 1.5 \times 10^{-19}$ coulomb (charge on an electron),

$$\frac{(V_{jp})^2}{(V_s)^2} = 0.053 \cdot \frac{R_1}{I_a} \cdot \frac{\mu^2}{\rho^2}.$$

Suppose that anode noise and grid noise are equally important; then

$$R_1 = \frac{I_a \rho^2}{\mu^2 \times 0.053}.$$

For a broadcast H.F. pentode,

$$\mu = 2000, \qquad \rho = 1{,}000{,}000,$$
$$I_a = 10 \text{ mA}$$

and R_1 is approximately 50,000 ohms. If grid impedances smaller than 50,000 ohms are used, the anode noise will predominate.

A quiet amplifier using broadcast type of valves must have grid impedances substantially greater than 50,000 ohms, let us say, at least 100,000 ohms.

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* "The Spontaneous Background Noise in Amplifiers due to Thermal Agitation and Schrott Effects," by E. B. Moullin, M.A., and H. D. M. Ellis, B.A., *I. E. E. Proceedings*, April, 1934.

Automatic Method of Factory Testing of Circuit Units

By E. P. G. WRIGHT

Standard Telephones and Cables, Ltd., London, England

SUMMARY: *This article describes the automatic testing of so-called plug or jack-in circuits. In place of following the usual practice of describing new testing methods in connection with a particular communication system, consideration is given to a generalized testing scheme which is readily applicable to many different types of circuits.*

IN an art changing as rapidly as communications, the manufacturer not only finds it necessary continuously to adapt his testing procedure to new developments, but also to older types of equipment required for extensions or other purposes.

In the past, the possibility of being called on to test a wide range of equipment necessitated maintaining various ranges of test boxes and valuable testing gear which was utilized only at infrequent intervals. Furthermore, in order to keep pace with inspection requirements, testing paraphernalia required overhauling and modification in advance of the production of a particular

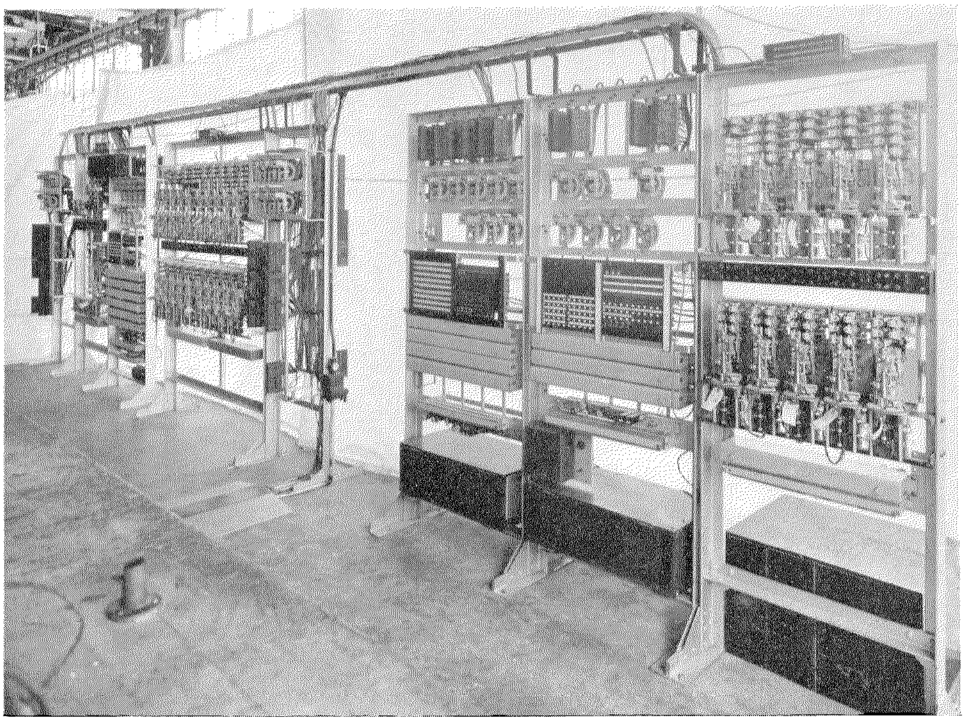


Fig. 1—General View of Automatic Testing Equipment. The Bays reading Right to Left are:
Inspection Rack for Final and Group Selectors with Bayonet Type Mounting;
Group Selector Test Rack;
Final Selector Test Rack;
Access and Cross Connecting Frame;
Final and Group Selector Inspection Rack with Channel Type Mounting;
Line Finder and Code Selector Test Rack;
Line Finder and Code Selector Inspection Rack;
Access and Cross Connecting Rack.

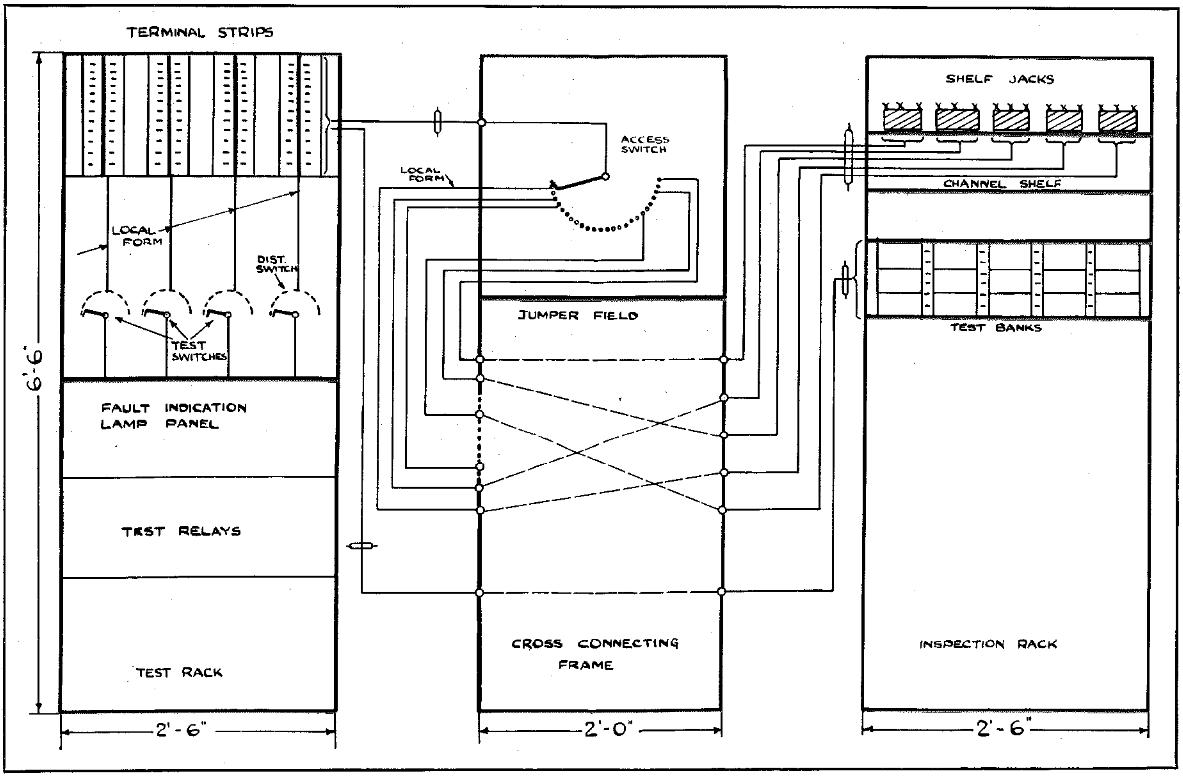


Fig. 2—Typical Automatic Test Rack Wiring showing Jumper Arrangements.

type of equipment. This ordered procedure could be followed in some cases; but, more often, the tailing out of previous designs held the test sets in use up to, or even beyond, the period when inspection of the new equipment was required. To handle this situation, it was therefore necessary to provide a large number of test sets which, in turn, involved additional planning work in maintaining up-to-date records and the danger of keeping on hand an unnecessary number of test sets in readiness for possible future demand.

To overcome these objections and to provide a generalized solution, an automatic testing equipment, shown in Fig. 1, has been devised. It includes a number of inspection positions which may be utilized for many different circuit conditions by changing cross connections on a permanent frame. The testing portion proper contains the testing elements necessary for handling all circuits of similar type, and jumpers are connected to access switches in such a way that only the appropriate tests are applied.

It will be evident that such an arrangement provides facilities for thoroughly and speedily testing any obsolete circuit, merely by running the necessary jumpers. This operation can be controlled by the Inspection Department when the load appears.

Fig. 2 shows the general layout of a typical testing suite of bays. The method of cross connecting will be readily appreciated.

The four fundamental considerations involved in the planning of this equipment were the following:

(1) Sufficient speed of functioning of the common testing circuits to handle the peak load output. This requirement necessitated complete automatic testing without manual assistance.

With the automatic testing equipment it is only necessary, after fitting the panel to be tested in the inspection rack, to operate the start test key and a second key which is individual to the inspection position. If the common test portion is already functioning, then only the second key is operated. A lamp is provided with each position in order that an indication may be given when the panel is tested correctly. The association between the common testing portion and the circuit to be tested is automatic, as is also the control of the correct tests to be applied. With certain fault conditions, it may be necessary to dial into the circuit repeatedly; therefore, to avoid interference with the common testing portion, certain outlets are wired only for manual testing.

(2) Provision of facilities for changing an inspection position for use with a new circuit. Such facilities must be isolated to avoid interference or changes in conditions on other test positions. In addition, the possibility of the whole or part of the common testing circuits being accidently rendered faulty must be eliminated.

(3) Facilities for adding further test positions for new circuits without disturbing the existing positions. In the equipment constructed, the wiring to the test relays was therefore not formed up but was run loose through jumper rings.

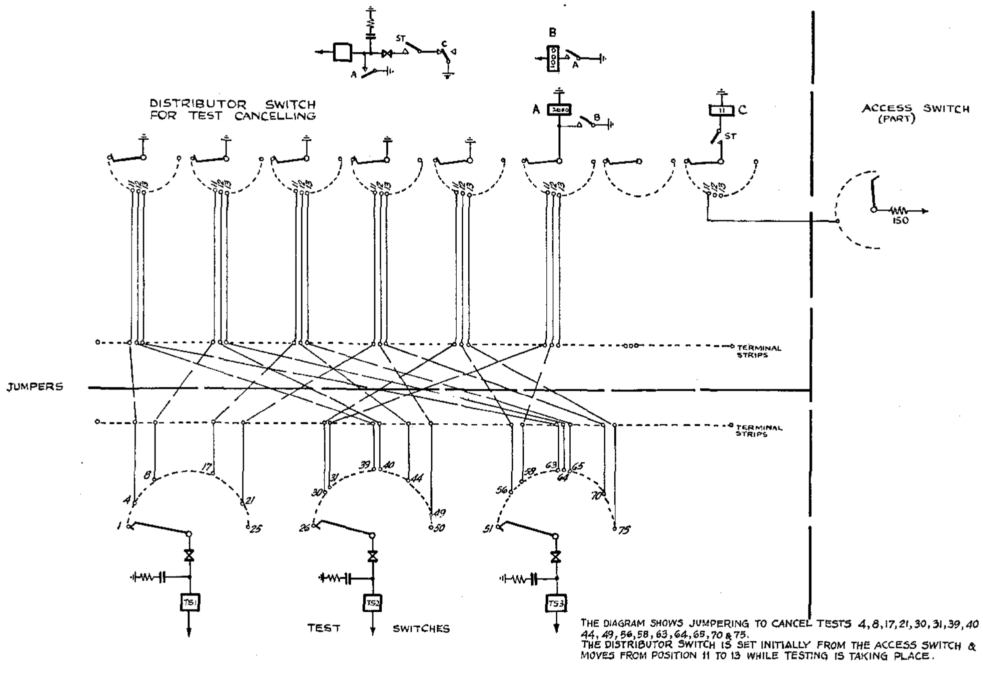
(4) Ready access to the front and rear of the panels under test for rapid checking of suspected causes of trouble. The design of the shelf is such as to provide maximum access to the wiring side.

Fig. 3 illustrates a schedule of tests carried out with the final selector test equipment. It should be understood that more than one position on the inspection rack may be allocated to any one circuit. Although columns 6 and 8 appear iden-

FINAL SELECTOR TESTING SCHEDULE

Test No.	Test	TYPE OF CIRCUIT											
		Lines:	200	200	200	200	200	100	100	100	100	200	200	200
		Trunk Grp:	2/10	2/10	over 20	Regular	Regular	2/10	2/10	2/10	Regular	11/20	over 20	11/20
		Metering:	Booster	4th Wire	4th Wire	4th Wire	Booster	4th Wire	None	4th Wire	None	4th Wire	Booster	Booster
1	"P" Lead Clear		/	/	/	/	/	/	/	/	/	/	/	/
2	Seize		/	/	/	/	/	/	/	/	/	/	/	/
3	"A" Relay Balance		/	/	/	/	/	/	/	/	/	/	/	/
5	Sending 10's Digit 9		/	/	Digit 0	/	/	/	/	/	/	/	Digit 0	/
6	Sending Pause		/	/	Spare	/	/	/	/	/	/	/	Spare	/
7	Sending Units Digit 9		/	/	"	/	/	/	/	/	/	/	"	/
9	Ringing Non Trip		/	/	/	/	/	/	/	/	/	/	/	/
12	Ringing Trip		/	/	/	/	/	/	/	/	/	/	/	/
13	Wiper Test		/	/	/	/	/	/	/	/	/	/	/	/
14	Booster Metering		/	Spare	Spare	Spare	/	Spare	Spare	Spare	Spare	Spare	/	/
15	Supy. "D" Release		/	/	/	/	/	/	/	/	/	/	/	/
16	Last Party Release		Spare	Spare	Spare	Spare	Spare	Spare	/	Spare	/	Spare	Spare	Spare
17	Release		/	/	/	/	/	/	/	/	/	/	/	/
18 -	As for Tests 1, 2, 5, 6, 7		/	/	/	/	/	/	/	/	/	/	/	/
23	Sub Busy		Spare	Spare	Overflow	--------------Spares----------------------						--------Overflow Busy---		
24	Busy Flash		/	/	/	/	/	/	Tone	/	Tone	/	/	/
26	Busy Hold		/	/	/	/	/	/	Hold	/	Hold	/	/	/
28	Release		/	/	/	/	/	/	/	/	/	/	/	/
29	Batt:C/o Seize (Even 100's)		/	/	/	/	/	Odd 100's	Odd 100's	Odd 100's	Odd 100's	/	/	/
30	"P" Lead Clear		/	/	/	/	/	/	/	/	/	/	/	/
31	Seize (Even 100's)		/	/	/	/	/	Odd 100's	Odd 100's	Odd 100's	Odd 100's	/	/	/
32	Digit Discrimination		---Spares---		Digit 5	----------------------Spares----------------------							Digit 5	Spare
33 -	As for Tests 5-7		/	/	/	/	/	/	/	/	/	/	/	/
37	P.B.X.1st Line Free		/	/	/	--Line Free--		/	/	/	Line Free	/	/	/
40	Ringing Trip		/	/	/	/	/	/	/	/	/	/	/	/
41	Wiper Test		/	/	/	/	/	/	/	/	/	/	/	/
42	HB Op: Cut thro' Even 100		---Spares---		/	---------------Spares---------------------						/	/	/
43	Release		/	/	/	/	/	/	/	/	/	/	/	/
44 -	As for Tests 30, 31, 33-35		/	/	/	/	/	/	/	/	/	/	/	/
49	P.B.X.1st Line Busy 2nd " Free		/	/	/	---Spares---		/	/	/	Spare	/	/	/
52	Release		/	/	/	/	/	/	/	/	/	/	/	/
53 -	As for Tests 44-48		/	/	/	/	/	/	/	/	/	/	/	/
58	P.B.X. Night Line Busy		/	/	--------Spares-----			/	Tone	/	Spare	/	Spare	/
59	Busy Flash & Hold		/	/	--------Spares-----			/	Hold	/	"	/	"	/
60	Release		/	/	/	/	/	/	/	/	/	/	/	/
61 -	As for Tests 53-57		/	/	/	/	/	/	/	/	/	/	/	/
66	P.B.X. Last Line Free		/	/	--------Spares-----			/	/	/	Spare	/	Spare	/
68	Release		/	/	--------Spares-----			/	/	/	"	/	"	/
69 -														
73	As for Tests 61-65		/	/	--------Spares-----			/	/	/	"	/	"	/
76	P.B.X.Busy. Busy Flash		/	/	--------Spares-----			/	Tone	/	"	/	"	/
77	Busy Hold		/	/	--------Spares-----			/	Hold	/	"	/	"	/
79	Release		/	/	--------Spares-----			/	/	/	"	/	"	/
80	"B" Relay Timing 46^V		/	/	/	/	/	/	/	/	/	/	/	/
81	Pause		/	/	/	/	/	/	/	/	/	/	/	/
82	Batty: Change over to 54^V		/	/	/	/	/	/	/	/	/	/	/	/
83	"B" Relay Timing 54^V		/	/	/	/	/	/	/	/	/	/	/	/
84	Pause		/	/	/	/	/	/	/	/	/	/	/	/
85	Finish End of Tests		/	/	/	/	/	/	/	/	/	/	/	/

Fig. 3—Schedule of Tests.



THE DIAGRAM SHOWS JUMPERING TO CANCEL TESTS 4,8,17,21,30,31,39,40 44,49,56,58,63,64,65,70 & 75.
THE DISTRIBUTOR SWITCH IS SET INITIALLY FROM THE ACCESS SWITCH & MOVES FROM POSITION 11 TO 13 WHILE TESTING IS TAKING PLACE.

Fig. 4—Schematic of Circuit for Cancelling Unnecessary Tests.

tical, the circuits must be placed only in their correct positions on account of differences in jack wiring and jack mounting.

Fig. 4 shows the arrangements for cancelling tests which need not be applied. The distributor switch is positioned from the access switch which determines the type of circuit to be tested. The wipers of the distributor switch connect a potential to positions of the test switches which advance through such cancelled positions in the same way as if the test had been correctly carried out. The sixth wiper to cancel a test causes relay operations resulting in advancing the distribution one step. In consequence, a particular setting of the access switch may be represented by several positions on the distributor switch. On the other hand, several positions on the access switch may be tied together if the same tests are to be cancelled.

For various reasons the product of the factory is improved by automatic testing. The automatic test is fundamentally more thorough. Wherever a fault is encountered and corrected, the whole cycle of tests must be rerun. Owing to the fact that common apparatus is employed, greater precision can be used in applying limiting conditions for impulsing and similar critical conditions. Voltage variations are introduced during the testing cycle so that timing tests for release lags and stepping speed may be carried out on extreme limits. Actually the tests applied are slightly more stringent than those used for functionally testing on site before acceptance.

Fig. 5 shows a typical weekly output chart from which it can be seen that an average of seven attempts are made on each circuit before acceptance. Approximately 20% are passed at the first attempt, so that the number of attempts on those found faulty is in the neighborhood of ten.

In Fig. 6 is given the approximate floor space requirements of the automatic testing equipment.

The advantages of this method of automatic testing may be summarized as follows:

(1) More rigorous testing under full automatic control, including among others:

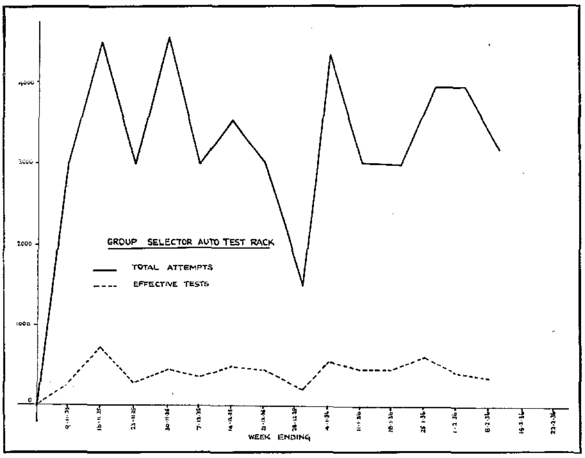


Fig. 5—Typical Weekly Output Chart.

- (*a*) Precision impulsing over limiting conditions.
- (*b*) Timing tests of relays to meet acceptance tests under practical conditions over the voltage range.
- (*c*) Hunting speed of group selectors.
- (*d*) Testing of selectors over voltage range of 46 to 54 volts with automatic voltage changeover.

(2) Rapidity.

For group selectors, it is estimated that the average testing time is 1½ to 2 minutes.

For final selectors, the average time is 2½ to 3 minutes.

For finders, the average time is 1½ to 2 minutes.

(3) Lamp display indicating fault on selector or panel.

(4) Automatic discrimination of tests to be applied to each type of selector via the access switches.

(5) Switch banks fixed to racks necessitating no adjustment of banks to selectors.

(6) Each jack position adapted to testing various types of selector by changing jumpers of the cross connecting frame.

(7) Automatic selection of next selector to be tested when one has been tested, a lamp display indicating selectors which have been passed.

(8) Ease of testing new selectors by the addition of test elements to the test circuit without interfering with testing which may be in progress.

(9) Manual operation cut down to a minimum, the only operation necessary being the adjustment of wipers to the banks.

(10) Provision for a check test before the selector is automatically tested. This may be desirable for checking such items as wiring to the selector test jacks, etc., or for clearing faults while the test circuit is in operation.

(11) Ready access to the selector wiring at the rear without jacking out the selector.

(12) An overall saving in:
- (*a*) Testing staff.
- (*b*) Floor space devoted to testing.
- (*c*) Cost per circuit tested.

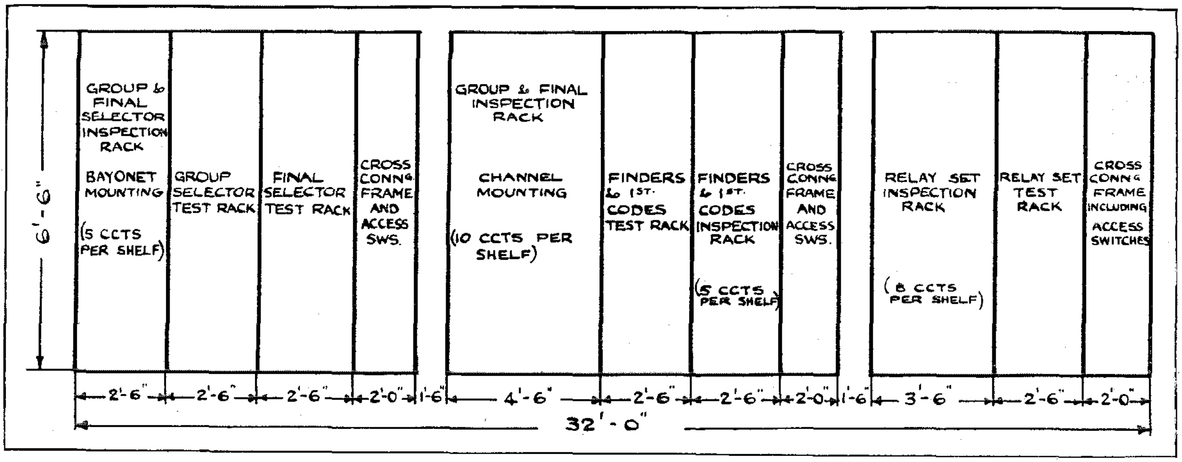

GROUP & FINAL SELECTOR INSPECTION RACK
BAYONET MOUNTING
(5 CCTS PER SHELF)
GROUP SELECTOR TEST RACK
FINAL SELECTOR TEST RACK
CROSS CONNG FRAME AND ACCESS SWS.
GROUP & FINAL INSPECTION RACK
CHANNEL MOUNTING
(10 CCTS PER SHELF)
FINDERS & 1ST. CODES TEST RACK
FINDERS & 1ST. CODES INSPECTION RACK
(5 CCTS PER SHELF)
CROSS CONNG FRAME AND ACCESS SWS.
RELAY SET INSPECTION RACK
(8 CCTS PER SHELF)
RELAY SET TEST RACK
CROSS CONNG FRAME INCLUDING ACCESS SWITCHES
6'-6"
2'-6"
2'-6"
2'-6"
2'-0"
1'-6"
4'-6"
2'-6"
2'-6"
2'-0"
1'-6"
3'-6"
2'-6"
2'-0"
32'-0"

Fig. 6—Typical Layout of Automatic Testing Equipment.

Hot Cathode Mercury Vapour High Tension Supply Equipment for Broadcasting Stations

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SUMMARY: *The respective characteristics and performances of the various types of high voltage d-c. supplies for high power radio transmitters are briefly reviewed and compared with those of the hot cathode mercury vapour rectifiers.*

Characteristics of a series of hot cathode mercury vapour valves designed by the L.M.T. Laboratories are given. The influence of the characteristics of the rectifier circuit on the valve performances is also considered.

Grid controlled hot cathode mercury vapour rectifiers are also reviewed and a description is given of a simple system for firing the valves.

Introduction

IN the decade just past, the advance in the technique of broadcasting has been very rapid and probably reflects a more intensive progress than any other section of electrical engineering. In the early days of broadcasting, the general level of power in the antenna of the more important stations was of the order of 500 watts, whereas to-day, stations of 100 kW. and above, are in operation; an advance in power of more than 200 times.

This advance, while rapid, has not been forced in any way, the various problems involved having been solved in the natural course of development. Perhaps the problem causing most delay in progress has been that of the thermionic valve, the ever increasing demand for higher antenna power always leading the already intensive development of higher power tubes.

The technique of high frequency amplification in broadcasting requires that the thermionic valves of the amplifier should have a power handling capacity of about four times the power supplied to the associated output circuit, in order to handle the peaks of modulation. When it is considered that for the largest stations a high tension supply is required of some hundreds of kilowatts the question of annual power cost becomes important and the problem of improving the efficiency of the power equipment requires greater attention.

It is interesting to recall that in the early types of broadcasters, which used thermionic valves of low anode voltage, it was possible to employ d-c. generators for the supply to the anodes, and naturally this practice tended to continue with the increase in anode voltage required by the progress of tube design. It became evident, however, that increased voltage introduced difficulties of insulation and commutation. Moreover, the high value of short circuit current brought in the added complication of special protection against short circuits. It has been said that the development and design of thermionic valves for high power lagged and, in order to increase power in the antenna, it became the practice to add more tubes in parallel, which was responsible for emphasising a phenomenon now generally known as "Rocky Point Effect." These effects were evidenced by a transient discharge, the intensity, other factors being equal, depending on the power capacity of the anode supply. With a d-c. generator, the short circuit current is limited only by armature reaction and the losses in the circuit, so that a Rocky Point Effect might easily have far reaching effects on the components associated with the tube, as well as on the tube itself, due to the excessive plate current. For these reasons, the d-c. generator without a limiting device was considered far from ideal. A temporary solution of the problem was found in the valve rectifier, which gives an inherent limitation of output due to saturation of the filament emission. The extreme reliability of the valve rectifier was such that it became extensively and almost universally used in broadcasting equipments. While the degree of reliability was high, it must be admitted that the efficiency was low, being of the order of 70% to 80% depending on the output and the circuit employed. This was not of great importance when considering transmitters of medium power, but with the demand for high power an increase of efficiency became imperative. The reason for the inherent low efficiency of the thermionic valve rectifier lies in the high voltage drop in the tube and, to a lesser degree, the filament power. These losses are dissipated in the form of heat which is carried away either by cooling water or by radiation, depending on the type of rectifier valve. The mercury vapour rectifier, which had been extensively employed for low tension services, was known to have a low voltage drop, and the problem arose as to the possibility of adapting that type of rectifier to high tension service with the object of increasing the efficiency of the high tension supply.

The earliest type of mercury rectifier to be adapted to radio transmitters consisted of an evacuated glass vessel at the bottom of which was a pool of mercury forming the cathode, the anodes being arranged in the glass walls of the tube. The rectifying action was caused by a discontinuous discharge between anodes and cathode, the anodes being at a high alternative potential. Auxiliary means were provided for starting the discharge or arc. When functioning correctly, the valve is filled with a blue glow, this being a typical characteristic of mercury vapour rectifiers.

The "Standard" 120 kW. equipment at Praha is equipped with a 500 kW. arc pool rectifier designed for 20,000 volts d-c. This particular rectifier employed eight valves in series, each valve having three anodes. The eight valves were enclosed in four oil-filled tanks and facilities were available for changing a tank in which a valve had failed. The remainder of the equipment consisted of high tension transformers and an autotransformer with an electrically-operated tapping switch by means of which the voltage could be varied on or off load. The rectifier was later fitted with arc pool valves having a grid electrode, the object being to reduce arc-backs, or reversed arc, and hence to improve the life of the valves. The addition of the grid electrode did, in fact, effect a great improvement and the rectifier is now giving satisfactory service with reasonable long valve life. In considering the advantages and disadvantages of the arc pool rectifier, it may be said that from the point of view of efficiency, simplicity, and reliability, it is good. The disadvantages are that the floor space required per kilowatt is large, and that the breakdown of a valve interrupts the service. The auxiliary gear required by the rectifier is relatively little and is not likely to cause breakdown of the main plant.

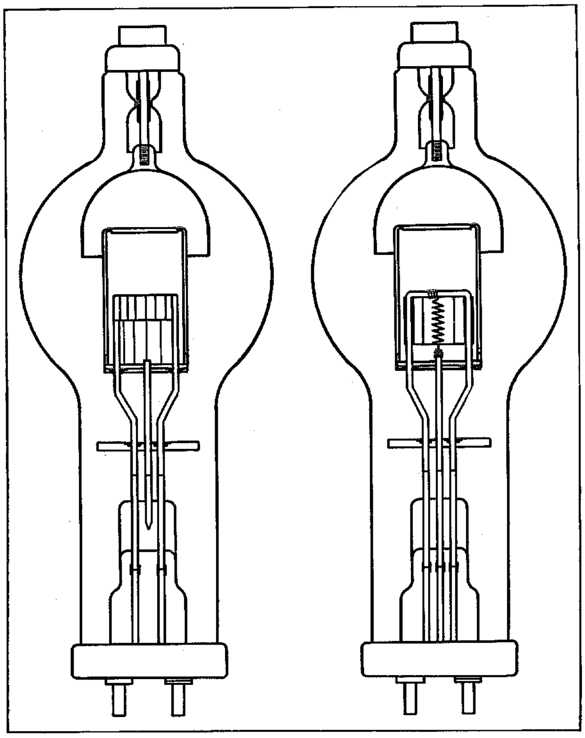

Fig. 1—Cross Section of Two Typical Hot Cathode Mercury Vapour Tubes. The Tube on the Left-Side is Directly Heated; the Other is Arranged for Indirect Heating.

The loss of 5 minutes service time consequent upon valve failure—a period which is quite average—must be regarded as a serious disadvantage and can only be avoided by the use of a complete spare or, alternatively, a spare half-rectifier, in which case the capital cost of the installation becomes impressive.

Another type of rectifier extensively used in low tension commercial undertakings is the mercury arc type in which the electrodes are contained in a metal tank which is kept continuously evacuated by means of associated pumping equipment.

This type of rectifier has now been developed for service working pressures up to 20,000 volts d-c. and a power of about 500 kW. The "Standard" equipment of the 120 kW. station at Budapest utilises a rectifier of this type and, as spare equipment, a "Standard" hot cathode rectifier is installed. In comparing the metal tank type of rectifier with other types, the economic factor becomes of extreme importance, since its capital cost is considerably greater than that of the renewable valve type as exemplified by the arc pool and hot cathode rectifiers. The capital cost is so high that in most cases a duplicate rectifier installation is prohibitive and recourse is necessary to a cheaper form of spare rectifier. One of the disadvantages of the tank type of rectifier, apart from the high initial cost, is that the auxiliary equipment for control purposes is complicated and a fault is likely to cause a lengthy interruption of service. This interruption is apt to be aggravated by the fact that the complexity of the circuit makes it difficult for ordinary station operators easily to diagnose a fault and to remedy it. The main body of the rectifier is not likely to give trouble, as the vacuum seals are soundly designed. The electrodes themselves are very durable but require renewal at intervals of about a year or more depending on the service conditions, an operation which would probably require a considerable time for completion and remaking of the vacuum. A factor which cannot be neglected, in view of the varying standards of competence in the maintenance personnel of radio stations, is that the rectifier is equipped with pumps and gauges, and although such gear is robust it is nevertheless intricate and of high precision.

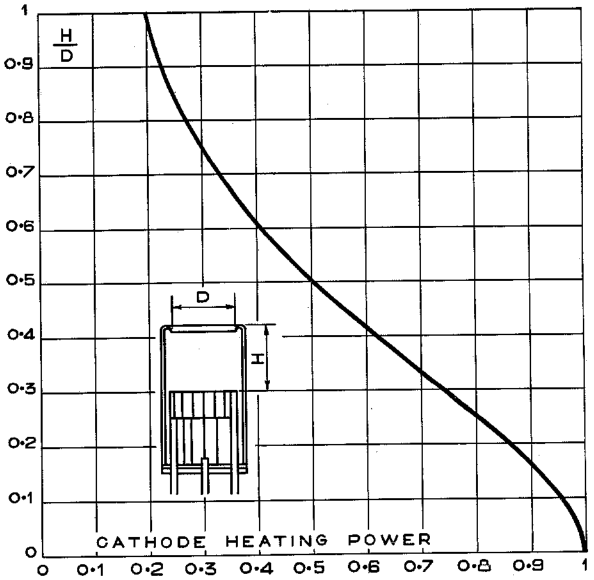

Fig. 2—Variation of the Heating Power Required to Bring a Cathode to Operating Temperature as a Function of the Height of the Screens.

A later development in rectifier design is the use of hot cathode mercury vapour valves. A series of such valves will be described, together with rectifier equipments using them, in the following pages.

Description of a Series of Hot Cathode Mercury Vapour Rectifiers and of Their Operating Characteristics

A hot cathode mercury vapour valve consists essentially of an anode and a cathode sealed into a glass bulb from which the air has been evacuated and into which a certain amount of mercury is introduced to neutralise the space charge between the cathode and the anode.

The cathode is generally composed of a nickel ribbon in valves having direct heating, and of nickel cylinders in valves having indirect heating. Special nickel alloys containing Cobalt, Titane or Aluminium have been employed as cathode material. So-called pertruded "nickel ribbon" and meshes of nickel wire also are used instead of plain nickel ribbon, to increase the adherence of the coating material which consists of a mixture of special alkaline earth oxides, this coating being obtained by dipping or spraying on the cathode a suspension of alkaline earth carbonates in an appropriate varnish. The emission current of such cathodes after they have been activated during the pumping procedure varies from 100 milliamperes to several amperes per watt of heating power, depending on the size of the cathode and the disposition of the screens provided around the cathode structure.

Fig. 1 represents conventionally a cross section of two typical hot cathode mercury vapour rectifier valves, one of the indirectly heated type and the other with a directly heated cathode. In both types the active part of the cathode is almost completely surrounded by screens, except towards the anode.

In large cathodes with proper screening, practically all the heat dissipated is radiated through the top aperture of the screens. The heating power required to bring the cathode to its operating temperature between 800° C. and 900° C. is approximately 20 watts per square centimetre of the screen opening for small types, and decreases to 5 watts per square centimetre for large types, nearly equal to the radiated power, which may be calculated, assuming that the top of the active part of the cathode radiates as a black body following the Lambert cosine radiation law.

The curve of Fig. 2 gives approximately the theoretical gain which may be obtained by decreasing the solid angle through which the active part of the cathode radiates, this being achieved by decreasing the distance between the top aperture of the screens and the active part of the cathode for a given diameter of this top aperture of the screens.

The anode is generally made of graphite to decrease its emissivity and is sealed into the glass bulb at the end opposite to the cathode.

In nearly all modern valves the anode encloses completely the top part of the cathode screens, such shape giving many advantages, one of which is that it prevents the formation on the inner walls of the bulb of a black deposit, which generally sets up arc-backs after a certain time of operation. This shape also localises the mercury glow inside the anode and cathode screens and decreases the space occupied in the valve by the ionised mercury vapour—an important point which largely affects the maximum rating at which the valve can safely be operated.

The dimensions of the glass bulb, anode, cathode, and those of adequate heat reflecting screens placed on the cathode support make the bulb temperature higher at the anode end of the glass vessel than at the cathode end. This causes the mercury in the tube to condense at the colder end near the cathode cap.

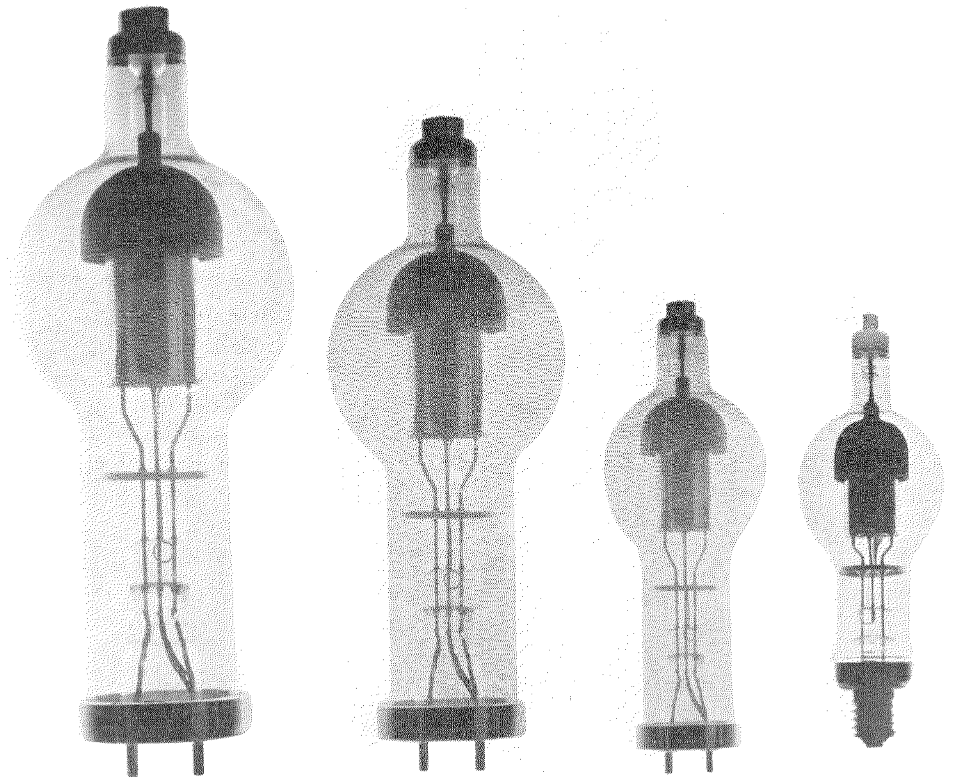

Fig. 3—A Series of Hot Cathode Mercury Vapour Rectifier Valves.

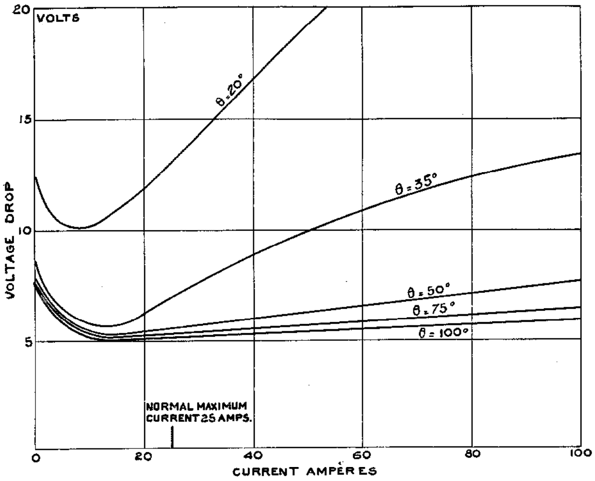

Fig. 4—Variation of the Volt Drop in a Hot Cathode Mercury Vapour Valve Versus the Load Current for Different Mercury Temperatures.

Fig. 3 shows a series of hot cathode mercury vapour rectifier valves having the features briefly discussed in the preceding paragraphs. The characteristics of these valves are given in the table below:

	Type L.8160	Type L.8161	Type L.8162	Type L.8165
Filament voltage..........	5 volts	5 volts	5 volts	5 volts
Filament current, about....	10 amps.	20 amps.	40 amps.	100 amps.
Peak anode current........	2 amps.	5 amps.	20 amps.	50 amps.
Peak inverse voltage.......	12,500 V.	20,000 V.	20,000 V.	16,000 V.

These tubes permit the realisation of rectifier equipments suitable for the high tension supply of radio transmitters having output powers ranging from a few hundred watts up to some hundreds of kilowatts, which is the maximum so far considered. Views of rectifier equipments using these valves and having outputs between 3 kW. and 500 kW. and voltages up to 30,000 volts are shown hereinafter.

The characteristics of hot cathode mercury vapour rectifiers are rated or defined by the majority of manufacturers and also in the above table, by the maximum instantaneous and the maximum inverse voltage which they can support. This definition is not, in the present state of the art, absolutely complete: different authorities have indicated that the maximum current and inverse voltage supported by a given type of tube depend enormously on the circuit in which the tube is used. The inverse current, i.e., the current passing across the tube during the period when the anode is negative, is a factor in determining the probability of a short circuit in hot cathode mercury vapour valves, and its influence on this performance is allied with the principle of the valve itself—the employment of an ionised medium for carrying the rectified current.

In a hot cathode mercury vapour valve, the ignition or striking voltage is that voltage which sets up ionisation by collision of the mercury vapour with electrons coming from the cathode. This tension, which lies between 12 and 20 volts, varies with the mercury vapour pressure and the emissivity of the cathode.

The voltage drop in a rectifier valve is the average value of the voltage which gives to the electrons drawn from the cathode the energy sufficient to reach the anode, i.e., the average value of the voltage which gives to electrons sufficient energy to bring molecules of mercury to the ionisation condition.

The fact that the voltage drop is less than the ignition voltage, shows that the mercury vapour does not return instantaneously to its deionised or neutral condition but passes through a certain number of intermediate levels. At any instant in a valve, the quantity of mercury vapour which is in a condition different from the neutral state depends not only on the value of the current at that instant but also on the value of the current at the time immediately preceding the moment under consideration.

During the working part of the rectifying cycle the voltage drop in hot cathode mercury vapour

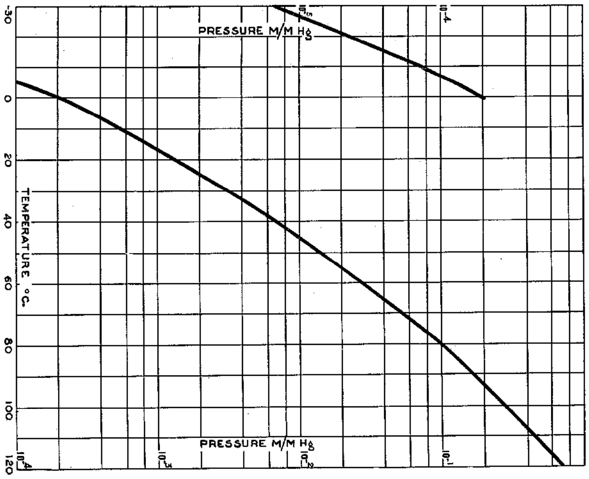

Fig. 5—Pressure Versus Temperature of Saturated Mercury Vapour.

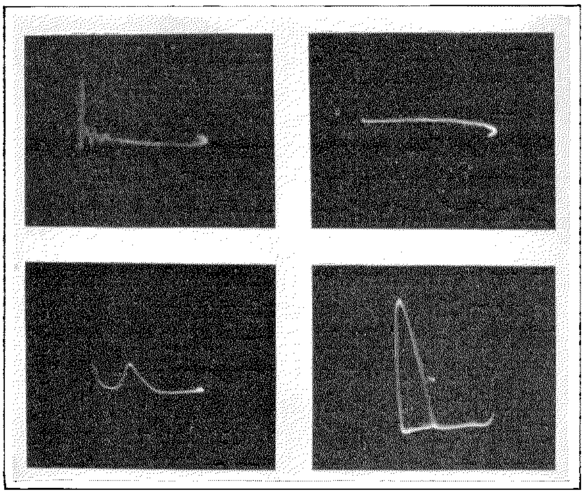

Fig. 6—Oscillographic Records of Inverse Current in a Hot Cathode Mercury Vapour Rectifier for Different Operating Conditions.

rectifier valves is generally between 15 and 5 volts. Fig. 4 shows the variation of the voltage drop of a given valve for various loads and mercury temperature conditions, and Fig. 5, the variation of the pressure of saturated mercury vapour versus the temperature of the condensed mercury. A voltage drop of more than 25 volts brings about the rapid deactivation of the cathode due to bombardment by positive ions of mercury.

The voltage drop in a hot cathode mercury vapour valve is affected not only by the pressure of the mercury vapour but also, for a definite load, by the volume of mercury vapour which becomes ionised when the rectifier carries current.

In valves having the construction shown in Fig. 1 in which ionisation takes place practically only inside the anode and cathode screens and not in the whole interior of the bulb, reducing the volume of ionised mercury vapour, or decreasing the section of the top aperture of the cathode screens, increases abnormally the voltage drop of the valve when the rectified current exceeds a definite limit, whilst the cathode emission may be considerably larger than is really needed. It may be said that for obtaining long life with sufficiently wide operating mercury vapour limits, the volume of the ionised mercury vapour should be at least 10 cubic centimetres per ampere of rectified current, and the density of the rectified current through the top aperture of the cathode screens should not exceed 0.5 to 1 ampere per square centimetre, depending on the rating of the valve considered.

At the moment of the apparent extinction of the valve, i.e., the moment at which the characteristics of the rectifier cause the rectified current in the valve to pass through zero, two opposing phenomena occur:

(1) The mercury vapour tends to return to its neutral state;

(2) The inverse voltage applied between anode and cathode tends to re-ionise the mercury vapour.

It may be said very approximately that, if the first effect is preponderant, the tube will support the inverse voltage; but, if the second tendency is greater, the valve will not support the inverse voltage.

This explanation supposes that the arc-back is not caused accidentally as, for example, by the formation of a cathodic spot on the anode due to the presence of mercury spots in the anode region, or electronic emission of the anode due to the presence of barium or other impurities on its surface. Fig. 6 illustrates oscillographic records of inverse currents measured for different operating conditions on one of the rectifiers herein described.

Depending on the shape and amplitude of the rectified current and inverse voltage waves, the instantaneous and average values of the inverse current may vary tremendously. The initial value of the inverse current just at the moment

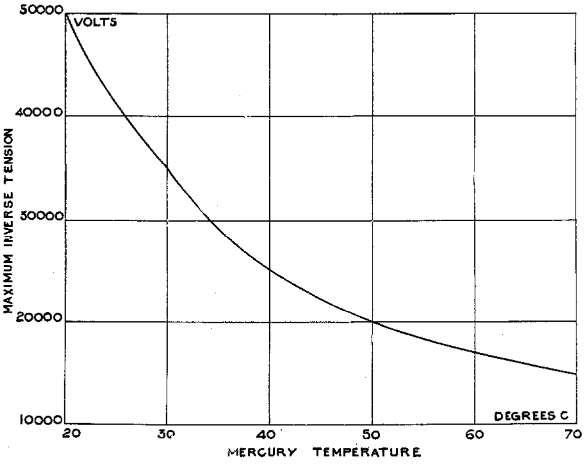

Fig. 7—Variation of the Maximum Inverse Voltage Supported by One of the Tubes Shown in Fig. 3 Versus the Temperature of the Condensed Mercury.

the inverse voltage starts to increase across the valve is usually considerably larger than the value of the inverse current during the remaining portion of the idle part of the cycle; generally, after a few milliseconds the inverse current drops to a very low value, whilst the inverse voltage applied across the valve continues to increase and passes through its maximum. In certain cases with very high inverse voltage and high mercury vapour pressure, the inverse current increases again and the curve shows a second maximum corresponding to the maximum of the inverse voltage wave.

Depending on the valve characteristics and operating conditions, the average value of the inverse current varies from 10^{-4} to 10^{-6} of the average value of the direct current whilst the peak value of the inverse current sometimes reaches 10^{-2} of the peak value of the direct current.

Following the hypothesis set forth above: To increase the inverse voltage which can be supported by the valves, it is necessary to increase the speed at which the mercury vapour returns to its normal state and to decrease the influence of the inverse voltage on the speed of recombination. This may be accomplished by

(1) Modifying the characteristics of the rectifier tube;
(2) Modifying the wave shape of the rectified current, inverse current, and inverse voltage.

For example, following (1) above, in a given tube the speed of recombination may be varied by changing the pressure of the mercury vapour, by increasing the surface of the electrodes, by decreasing the volume of ionised vapour, or by providing auxiliary electrodes biased at suitable potentials. Such means are very efficient but if

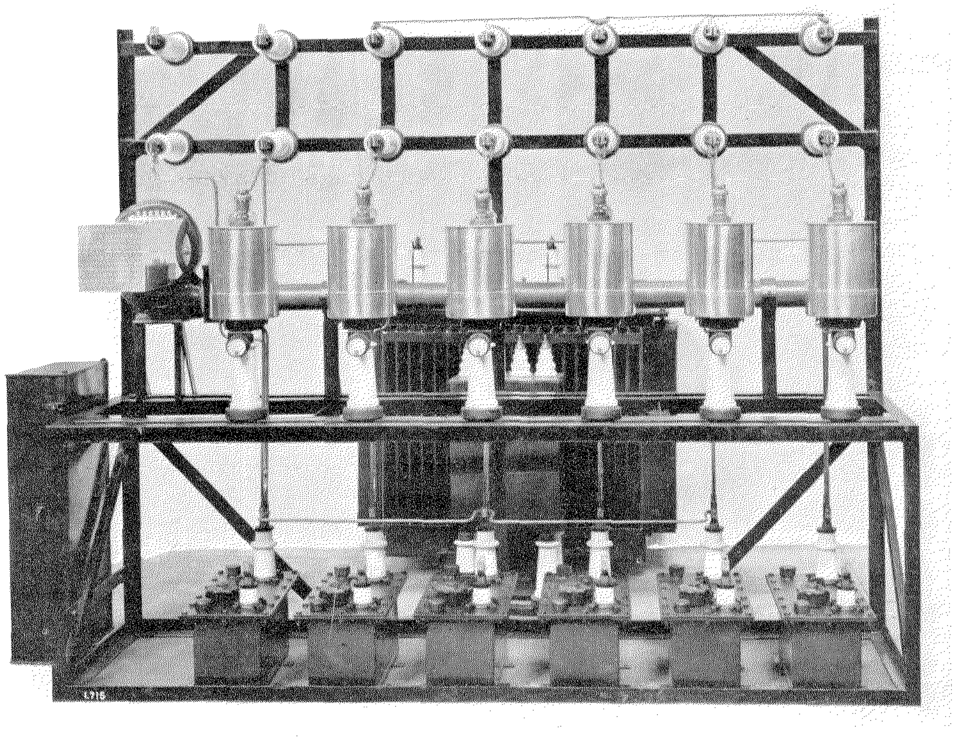

Fig. 8—The Frame of a Six Tube Rectifier Unit Equipped with a Constant Temperature Air Blowing Device.

not adequately adapted to the valve rating may considerably shorten the valve life; for, during the active and idle parts of the rectifying cycle, they may increase the bombardment of the active part of the cathode and cause its rapid deactivation.

The variation of the mercury vapour pressure caused by change in the temperature of the condensed mercury is one of the most important factors in the operation of hot cathode mercury vapour rectifiers. Too high a mercury vapour pressure is favourable to the operation of the cathode and, for a given rectified current, increases its life and decreases the voltage drop in the valve; but an increase of the mercury vapour pressure decreases the maximum inverse voltage supported by the valve and causes the valve to arc back. Fig. 7 gives an idea of the variation of the inverse voltage versus the temperature of the condensed mercury for one of the valves shown in Fig. 3. Contrariwise, an excessive decrease of the mercury vapour pressure increases the voltage drop above the critical value, causing abnormal bombardment of the cathode which results in its rapid deactivation. Furthermore, excessively low mercury vapour pressure is generally the reason for severe over-voltages which are sometimes encountered with mercury vapour rectifiers.

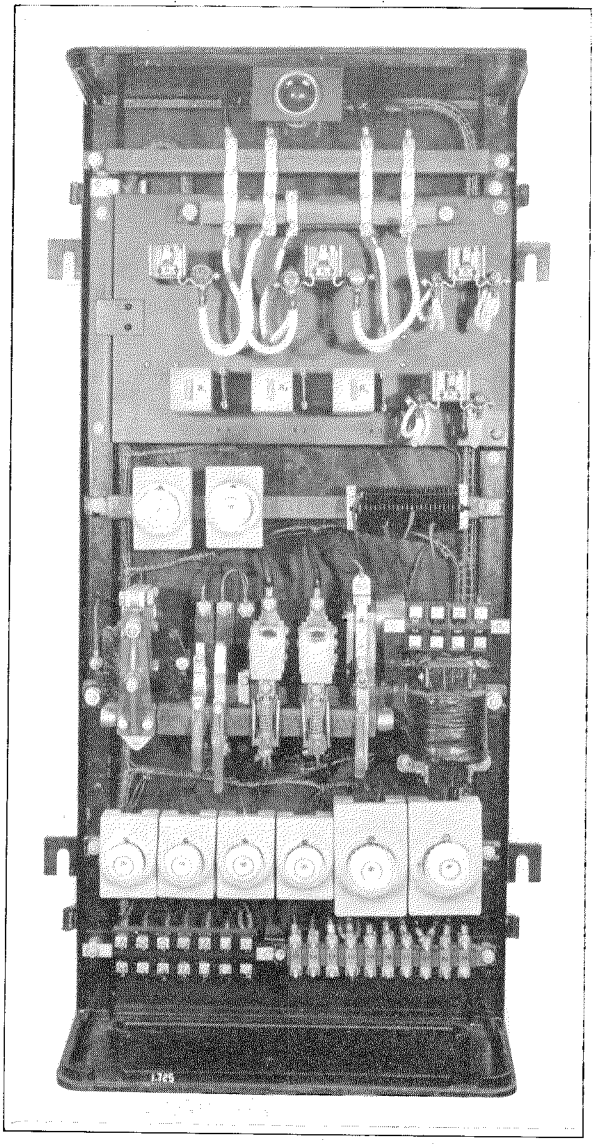

Fig. 9—Contactor Rack Used for the Control of the Constant Temperature Air Blowing Device Shown in Fig. 8.

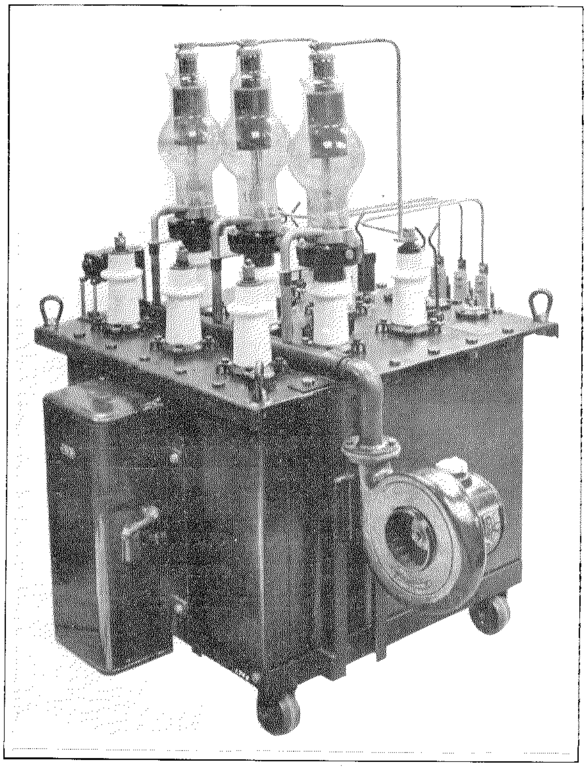

Fig. 10—10 KW. Rectifier Unit with Forced Air Cooling at Ambient Temperature.

With nearly all hot cathode mercury vapour valves in general use, the temperature of the condensed mercury is about 10 to 15° C. above the ambient temperature, provided that free air cooling by natural convection is possible around the valve. The minimum and maximum operating mercury temperatures generally given to satisfy the conditions mentioned above are 20° C. and 60° C., respectively, depending on the current and inverse voltage ratings adopted, thus fixing the limits of ambient temperature between 10° and 50° C.

In order to maintain the operating temperature of large rectifier valves at the optimum value, a system of air circulation at constant temperature may be employed. The system is such that the temperature of the air blown on the coldest part of the rectifier bulb is kept within close limits; for example, ±2° C. of the optimum temperature which is generally between 30° C. and 40° C. An air circulation system of these characteristics extends considerably the range of ambient temperature giving satisfactory operation of the rectifier, as it is obviously possible to maintain the optimum temperature on the valve for any ambient temperature below the maximum, which of course depends on the design of the rectifier valve used and on the load conditions.

A constant temperature air circulation system is particularly efficacious in cases of low ambient temperature as a few minutes of operation under too low mercury vapour pressure would suffice to damage irremediably the emission of the cathode of hot cathode mercury vapour valves. Fig. 8 shows the assembly of a six tube rectifier unit equipped with a constant temperature air blowing device. It will be seen that the valves are supported by insulators fixed to the frame, the filament transformers being mounted below the valves. By means of a fan mounted on the left side of the frame the draught is forced to pass through heating resistances and is directed on to the valves through suitable piping and nozzles. Shields are placed around the valves in order to avoid irregular convection of the surrounding air in case of low ambient temperature.

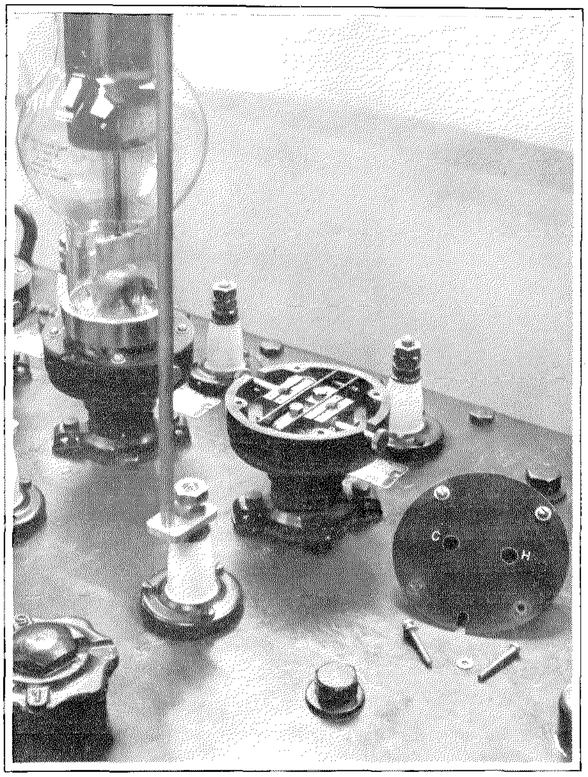

Fig. 11.—Special Socket for Mounting Hot Cathode Mercury Vapour Valves on Transformer Bushing.

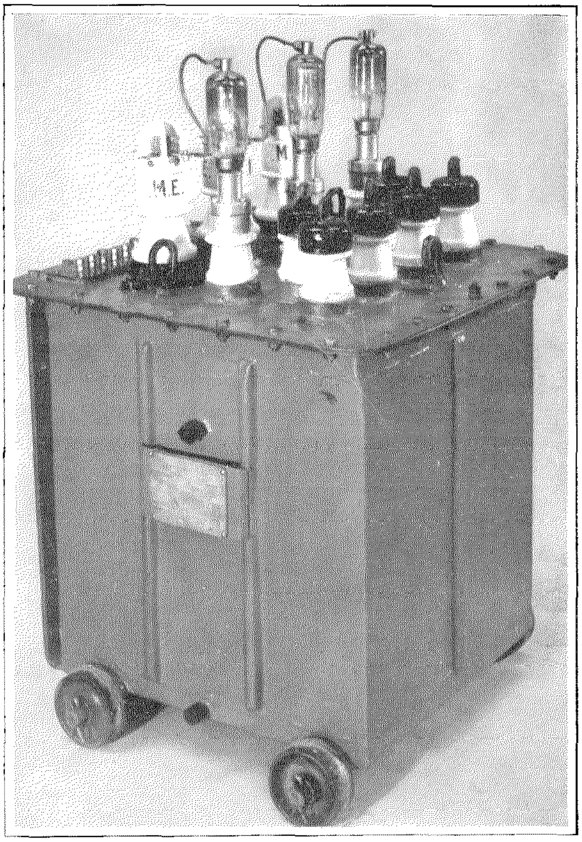

Fig. 12—3 KW. Rectifier Unit.

The relays used for controlling the power dissipated in the heating resistances so as to maintain constant the temperature of the air blown are assembled on a rack shown in Fig. 9, which also contains the relays for delaying the application of the voltage to the anodes of the valves until the cathodes have reached their operating temperature at the starting up of the rectifier.

Such cooling systems, which are essential for high power rectifiers or for special ambient temperature conditions, are of course not always needed. The rectifier shown in Fig. 10 is a complete and self-contained 10 kW. unit which, after being connected to suitable a-c. supply, is able to deliver smooth d-c. current. It comprises mainly an oil filled tank containing the filament heating transformers of the valves, the high tension transformer and the d-c. smoothing choke coils. The valves are mounted directly on the cover of the tank by means of suitable sockets sealed on the porcelain high tension bushings.

A contactor rack is mounted on the front side of the unit and comprises the contactors, overload relays, and time delay relay necessary for the operation of the rectifier. On the side of the unit is fixed a fan which, by means of appropriate piping and nozzles, blows air on the tubes at the ambient temperature. The fan is started automatically when the ambient temperature exceeds a fixed value, generally about 25° C., by means of a thermostatic relay seen on the left of the illustration behind one of the porcelain terminals.

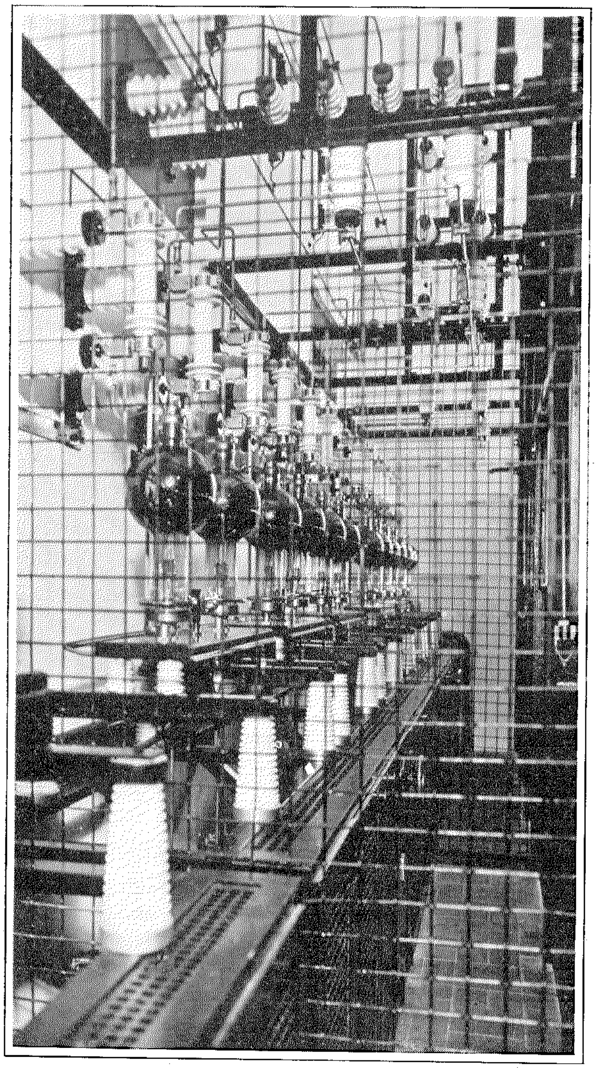

Fig. 13—250 KW. 20,000 Volt Rectifier Supplying the Plate Voltage to the Power Valves of the Kalundborg 60 KW. Broadcaster.

Fig. 11 shows the details of the special socket used for mounting the valve direct on the bushing of the unit.

This type of construction in a self contained unit, as exemplified above, has proved to be highly economical and reliable for rectifiers from 3 to about 50 kW., and furthermore makes it possible to install rectifiers in cubicles as is done for high tension transformers.

Fig. 12 represents a 3 kW. rectifier unit of the same design but, in this case, no provision has been made for forced air cooling, air cooling by natural convection being considered sufficient for the output requirements and range of ambient temperature considered. Fig. 13 shows a 20,000 volt rectifier installed at Kalundborg, Denmark, for supplying the voltage to the anodes of the power valves of a 60 kW. broadcaster.

The air cooling conditions required by hot cathode mercury vapour valves are often overlooked, especially when they are mounted in closed cabinets or units. In such cases special care should be taken to insure that the real temperature of the condensed mercury is within the specified limits. The air temperature inside such units, after some hours of operation, may be considerably above room temperature and, in addition, the cooling of the valves by natural convection is obviously less when they are closely surrounded by other components of the equipment.

Another important point to be observed, when hot cathode mercury vapour valves are mounted in closed units is that the disposition of the windows or louvers provided for air circulation should be such that the incoming fresh air is blown or drawn in at the bottom of the unit rather than in front of the anode region of the bulb of the rectifier valves, since the latter will cause the mercury to condense in undesirable regions and consequently promote arc-back conditions.

Apart from the factors which directly affect the valves, such as the mercury vapour pressure, the cathode emission, voltage drop, etc., there are other factors which can affect their operation. For instance, by changing the characteristics of the rectifier circuit in which a given valve is used, it is possible to change enormously the manner in which the valve will support the inverse voltage; in other words, a given valve may operate perfectly in a certain rectifier equipment whilst, for the same output in another less suitable circuit arrangement, the same valve may arc back almost continuously.

As stated previously, in hot cathode mercury vapour valves, the residual ionisation during the idle part of the rectifying cycle is one of the important factors which affect the maximum inverse voltage they can support. At any instant of the working part of the rectifying cycle, the quantity of mercury vapour ionised in a valve depends on the instantaneous value of the direct current and, when the current decreases, the quantity of ionised vapour decreases also, but with a delay; and it is evident that, if the direct current stops abruptly, the deionisation time is longer than if the current decreases progressively. The wave shape of the inverse voltage applied to the tube can also change the speed of deionisation of the mercury vapour. If, immediately after the extinction of the valve, the inverse voltage increases very rapidly, its influence can easily become more important than that of the recombination of the mercury vapour.

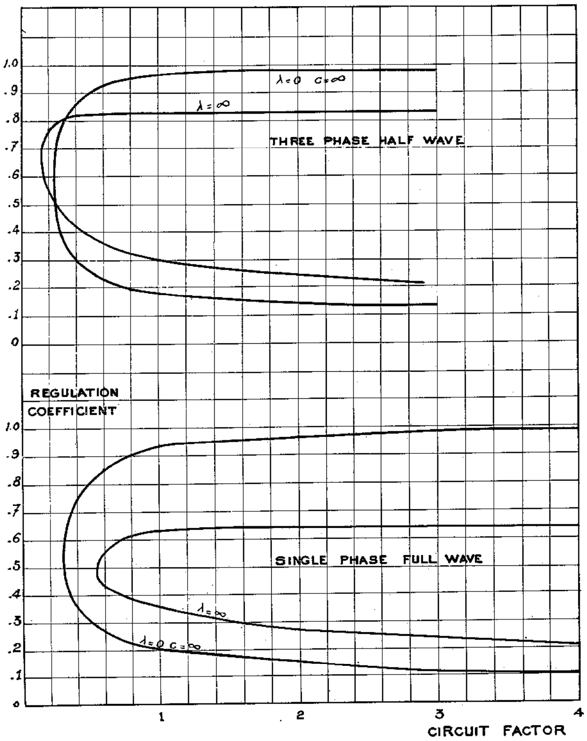

Fig. 14—Representing the Variation of the Fatigue of the Rectifier Valves in 3-Phase Half Wave and Single-Phase Full Wave Arrangements Versus the Regulation Coefficient of These Circuits for the Two Following Extreme Conditions: Filter Beginning with an Infinite Reactor or Beginning with an Infinite Condenser.

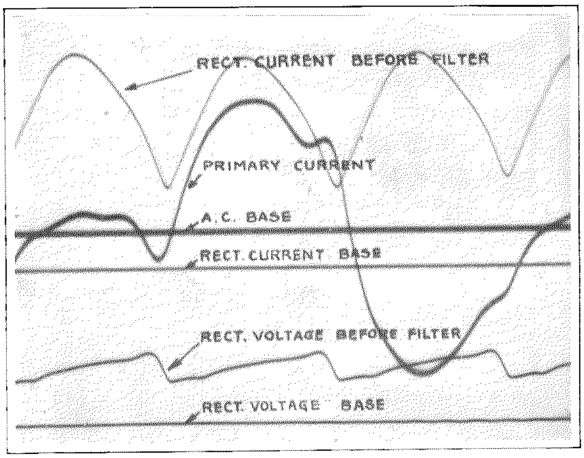

Fig. 15 A

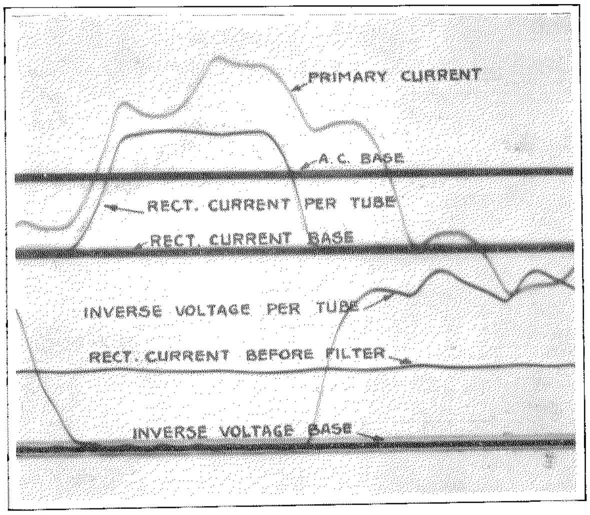

Fig. 15 B

Figs. 15 A and B—Primary Current, Rectified Current Per Valve, and Inverse Voltage Waves of a 10,000 Volt 12 Ampere, and a 5,000 Volt .5 Ampere Rectifier Under Load.

These different considerations have inspired an attempt to evaluate the fatigue of rectifier valves in different operating conditions, the object being to define the characteristics of rectifier circuits so as to give the most favourable conditions. The fatigue of a valve under given operating conditions has been defined arbitrarily as being a complicated function of the peak rectified current, peak inverse voltage, rate of change of the direct current, and inverse voltage just before and after the moment at which the direct current ceases to flow in the valve.

To illustrate one of the effects of the circuit characteristics, Fig. 14 gives in arbitrary units the variation of the fatigue of the rectifier valves for two conventional circuits in terms of the regulation coefficient of the rectifier circuits under consideration. For each type of rectifier circuit there is a minimum coefficient of fatigue and, evidently, it should be the aim to reach this minimum, which is in fact possible. It must be stated that it does not necessarily follow that conditions of high efficiency and good power factor cause less strain in the tube.

Another important factor which may affect seriously the behaviour of rectifier valves is that the maximum inverse tension which can be supported by mercury vapour valves decreases as the frequency of the applied alternating supply increases, the effect being due to the appreciable time required by the mercury vapour to become deionised. The maximum inverse tension in the valve increases rapidly after the cessation of the normal current, the rate of increase depending on circuit design, which can be modified. If, however, a high frequency voltage be superimposed on the low frequency which is to be rectified, the excitation of the mercury vapour will persist longer in the tube after the stoppage of the normal electronic current, so that the maximum inverse tension which can be carried by the valve will be reduced. Therefore, in rectifiers used for supplying anode voltage to high frequency amplifiers, as, for example, in radio broadcasting stations, it is absolutely necessary to avoid, by suitable filter circuits and screens, the picking up or the return of radio frequency on the rectifier valves.

The complete theory of mercury vapour rectifiers has been fully treated by several authorities and it is not within the scope of this article to reproduce the extensive calculations made. It is, however, of interest to insist on the influence of circuit design on the performance of rectifier tubes; in particular, the effect of the transformer and filter circuits, since a frequent source of error has been to design a filter circuit without regard to its effect on the operation of the rectifier. In other words, in a mercury vapour rectifier, it is not only necessary to consider the factors which make up the characteristics external to but applying to the rectifier, such as regulation, power factor, efficiency, and suitability of the filter circuit; but, in addition, the influence of the rectifier characteristics and of the filter should be examined from the point of view of the operation of the rectifier valves themselves.

An effect which may arise and which may affect profoundly the operation of rectifier valves, is the tendency of the transformer feeding the rectifier to oscillate. This tendency is present because of the rapid change in the current passing through the transformer windings when feeding a rectifier. The greatest change takes place at the moment when the current in each winding, after passing through its maximum, decreases and then ceases abruptly; the value of the current change may be of the order of 100,000 amperes per

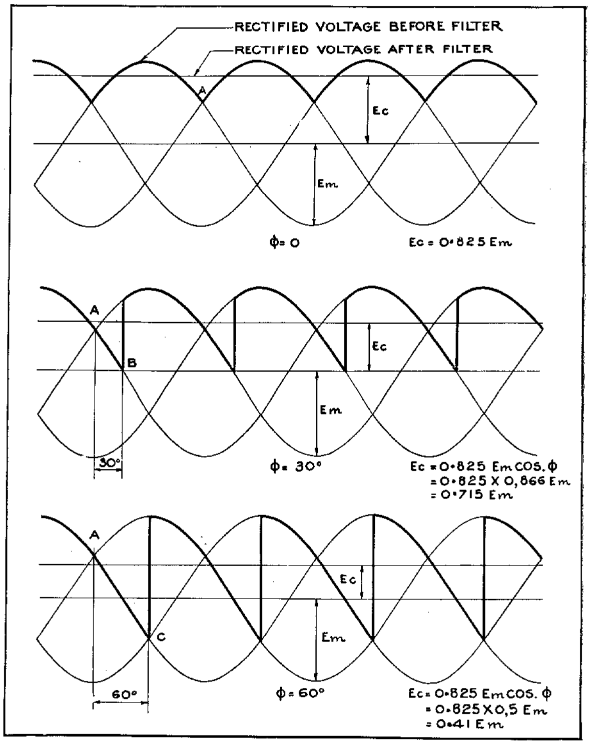

Fig. 16—Variation of the Wave Form of the Rectified Voltage of a 3-Phase Half Wave Grid Controlled Rectifier when the Firing Delay of the Grids is Increased.

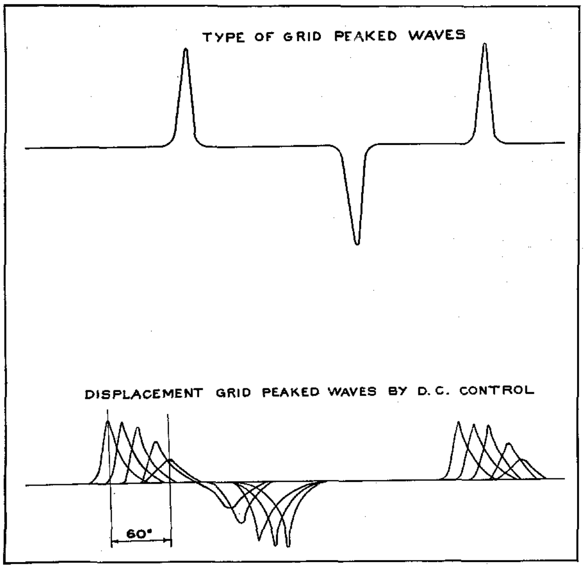
TYPE OF GRID PEAKED WAVES
DISPLACEMENT GRID PEAKED WAVES BY D. C. CONTROL
60°

Fig. 17—Wave Shape of the Peak Wave used for Firing Grids and Displacement of the Peaked Waves by D-C. Control.

second for 500 kW. rectifiers. This abrupt cessation of current may excite oscillations in the transformer windings, always assuming that the windings are susceptible, and it may be advantageous on transformers used with mercury vapour rectifiers to adopt a system of construction used on so-called antiresonant transformers. It has been found, however, that the application of suitable damping circuits or surge absorbers is in most cases quite satisfactory in suppressing unwanted oscillations.

In order to protect the transformer winding from surges which might arise at the moment that the supply voltage is switched on to the transformer, the switching mechanism, which may be either a circuit breaker or contactor, should be operated in two or more steps. The first step switches on the power to the rectifier transformer through resistances, and the second step, which occurs shortly afterwards, short circuits these resistances. Fig. 15 shows oscillographic records of the a-c. current, rectified current, and inverse voltage of some of the rectifier units illustrated herein.

Hot Cathode Mercury Vapour Grid Controlled Rectifiers

An important development of the hot cathode mercury vapour rectifier is the introduction of a grid electrode as a means of controlling the output, but it would appear that the development of this type of rectifier is not as yet sufficiently advanced to permit regular operation for broadcasting services. However, it may be said that grid controlled hot cathode mercury vapour rectifiers will certainly be used extensively in the future, inasmuch as the added facilities they render possible, whilst not essential for rectifiers used for radio broadcasting, give greater flexibility to the equipment at reasonable cost.

The effects of a grid electrode as fitted to mercury vapour valves for high tension rectifiers are as follows:

(1) To prevent the current from starting between anode and cathode, even when the anode is positive in respect to the cathode by a higher value than that which would have ignited the valve had there been no grid electrode. This result is accomplished by making the grid negative with respect to the cathode;

(2) To cause immediate ignition of the valve, the anode being positive with respect to the cathode. This result is obtained by making the grid positive with respect to the cathode;

(3) Once the valve is ignited, the ignition cannot be stopped, or the value of the rectifier voltage changed.

The above effects are well illustrated by the oscillograms reproduced in Fig. 16, which show the wave form of a rectified voltage recorded in front of the filter circuit of a three-phase rectifier assumed to be without voltage drop. The top curve shows the wave form from an ordinary rectifier without grid control, ignition taking place at A. The middle curve shows the effect of retarding the ignition from point A to point B by means of the grid, the angular displacement between points A and B being the angle of delay of excitation. In the lower curve the ignition is still further retarded to the point C. In both the last two cases the excitation of the grid was a positive peaked wave timed to occur at the right instant. Now the value of the grid electrode as a means of varying the rectified voltage is that, for a given angle ϕ, the resultant output voltage will be equal to the output voltage given by the same rectifier, but without grids, multiplied by the cosine of ϕ. It has been shown by the oscillograms

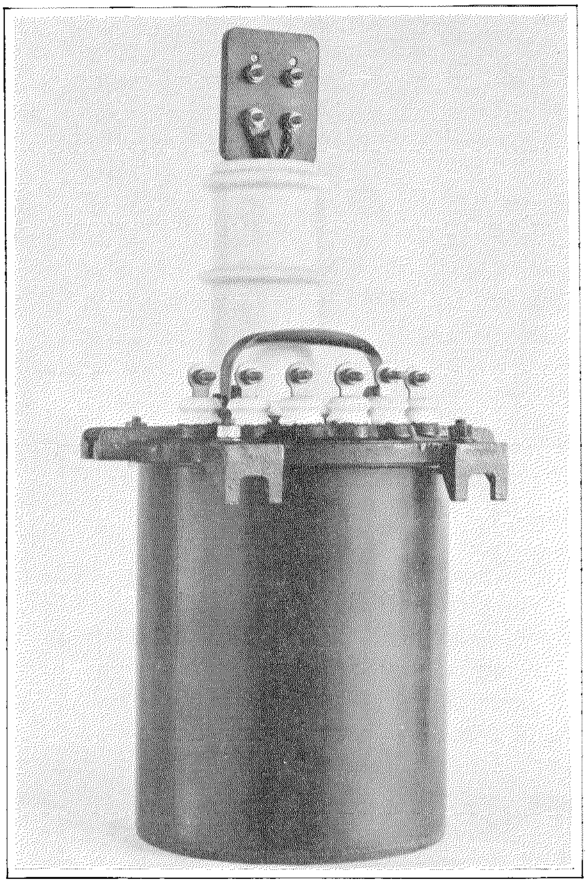

Fig. 18—Peak Wave Transformer Used for Firing Grids of Hot Cathode Mercury Vapour Valves. The Grid Control Wiring is that Connected to the High Voltage Insulated Terminal. The Other Terminals are Low Tension A-C. Excitation and D-C. Control Windings.

that the variation of angle ϕ controls the mean value of the output rectified voltage. This variation is theoretically from zero to maximum for a variation in ϕ from zero to 90°.

Furthermore, the effect of the grid is such that when it is connected to the cathode, or adequately biased, the valve will not ignite even when the anode is positive with respect to the cathode. As soon as ignition has occurred, the grid takes up a potential approximately that of the cathode until anode current ceases to flow as the applied voltage changes in sign. In every case, to obtain ignition of the valve, the grid must be given a positive potential for a very short interval of time.

The properties of the grid electrode afford an immediate protection for the valve itself and facilitate the operation of a system for limiting and switching off overloads or short circuits, since it is only necessary to suppress the grid excitation in order to stop the further ignition of the valve.

Among the many systems possible for the excitation and control of grid controlled hot cathode mercury vapour valves, the system discussed below has been chosen as it does not include any rotating parts or moving relays. A peaked wave, as shown in Fig. 17, is used for the excitation of the valves.

The chief component required for the system of the production and control of this peaked wave is a transformer shown in Fig. 18. This transformer has a special magnetic system partly made of Permalloy, and is supplied with an a-c. voltage from the same supply as that to be rectified. A direct current passes through one of the windings and is used as a control. Each time that the a-c. wave through one winding changes in sign, the flux of the core is reversed and a peaked wave is produced in a third winding. If now the value of the direct current in the control winding is increased, the peaked waves are displaced with respect to the a-c. cycle. The effect is well illustrated in Fig. 17, which is a reproduction of an oscillogram of the output voltage of the transformer. In this case the peaked wave was displaced by 60° for a total change of 200 ampere-turns in the control winding. A further increase in the value of direct current has the effect of saturating completely the core system with the result that peaked waves are no longer produced and the grid controlled rectifier valves are no longer excited. The value of this principle of variation of output may be more closely understood by taking as an analogy a separately excited d-c. generator. In the case of the generator, the variation of the field excitation may be such as to vary the voltage output from zero to maximum. With a grid controlled rectifier using this special transformer, the voltage output may be adjusted by changing the value of ampere-turns in the d-c. winding, thus displacing the grid peaked waves. In the same way, it is equally easy to obtain compounding of a rectifier by passing a portion of the output current through the control winding. The power required for such auxiliary controls is about 1/100 of the power required in a d-c. generator to give the same facilities. Fig. 19

is a simplified schematic of a three-phase rectifier using grid controlled rectifier valves.

The auxiliary dry rectifier shown in Fig. 19 is supplied with a-c. power from the main supply, the output of the rectifier feeding into a potentiometer, which is in turn connected to the control winding of the transformer for producing peaked waves for the grid excitation. The object of this small rectifier and potentiometer is to give a control of the output by displacing the peaked waves and hence, as already shown above, changing the output. It is evident that the auxiliary rectifier and potentiometer might be replaced by a d-c. regulator such as is used to control rotating machinery and, in this way, constant voltage output could be obtained from the rectifier, and much more economically, inasmuch as the power capacity of the regulator need only be quite small.

Following the analogy of the d-c. generator, it will be shown that a grid control rectifier may be compounded in a much simpler manner than is the case with a rotating machine. In the latter case, compounding is obtained by passing a portion of the output current through the field circuit in a direction and at an intensity required by the conditions. In the case of a rectifier, however, equivalent results may be obtained by using a fraction of the output power in the control winding of the peak wave transformer. The order of power required to give complete control is from 0.1% to 0.001% of the rectified power.

Probably one of the most valuable features which can easily be applied to a grid control rectifier is the facility for breaking overload conditions instantaneously. In this respect the analogy of the d-c. machine cannot be followed since the system used for a grid control rectifier is infinitely more simple and flexible. In considering the case of a machine, it is well known that auxiliary means have to be provided for tripping

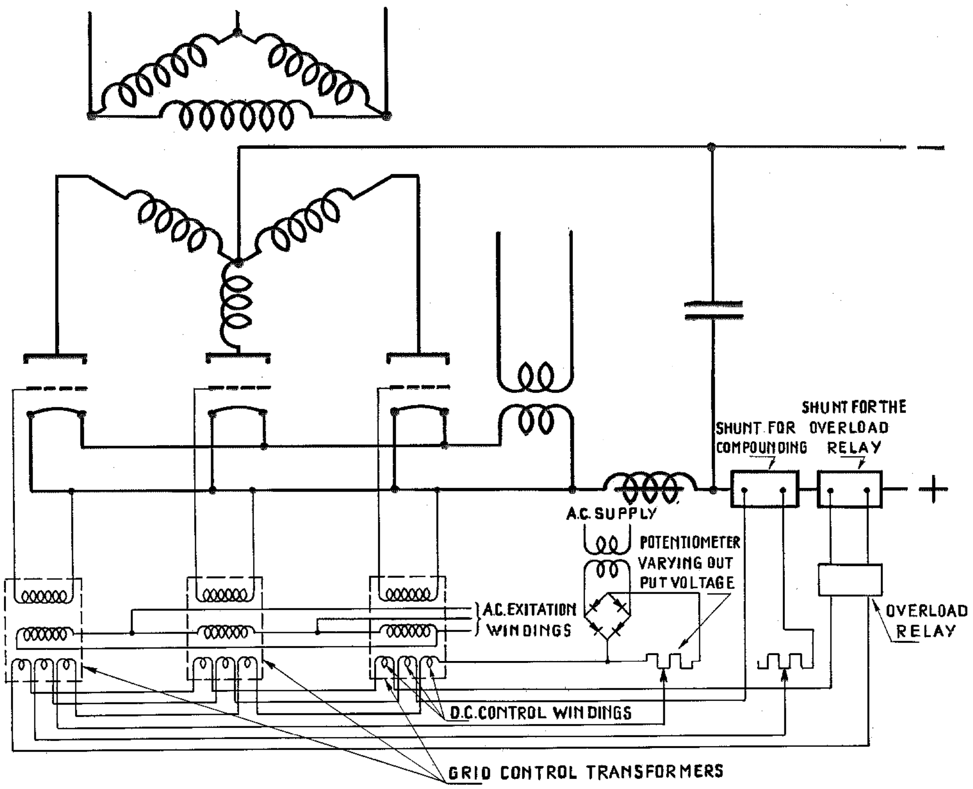

Fig. 19—Simplified Schematic of a Grid Controlled 3-Phase Half Wave Rectifier.

a short circuit or overload and such means are generally relatively slow-acting and expensive. On the other hand, the grid control rectifier requires but the suppression of the grid excitation for achieving the same object and this with a speed greatly superior to that of the associated equipment of the machine.

In the system under consideration, which is free from moving parts, the tripping device consists of a mercury vapour relay in a special circuit arrangement comprising a Wheatstone bridge, one of the arms of the bridge being connected to the load circuit. The arrival of a short circuit or overload upsets the balance of the bridge and instantly sets the valve relay into operation, this, in turn, suppresses the grid excitation of the main rectifier which immediately ceases to function.

In systems in which mechanical devices are permitted, the valve relay is replaced by a small mechanical relay having very low inertia and capable of operation at high speed. On the occurrence of a short circuit or overload, the relay operates and suppresses the grid excitation.

Such systems may be arranged to break down short circuits in less than 20 milliseconds and, since high voltage rectifiers used for radio transmitters include important smoothing circuits, the overload relay suppresses the grid excitation of the valves before the rectified current fed into the smoothing circuit has appreciably increased, whilst the transient output current of the filter is several times the normal.

Conclusion

The possible varieties of rectifiers using hot cathode mercury vapour valves are extremely numerous since different combinations and numbers of valves may be used in many different types of circuits. The fundamental advantages of a rectifier using hot cathode mercury vapour valves are simplicity and low first cost; the reliability is very good but is, of course, handicapped by the necessity for valve renewal. Unlike the arc pool type, the failure of a valve does not cause an interruption in the service, and a failed valve is, in any case, quickly replaceable. The low initial cost of the rectifier permits the addition of spare equipment without making the whole installation uneconomic.

To sum up, therefore, the general characteristics of the most popular types of rectifier dealt with above, it may be said that the efficiencies and power factors are of the same order for all three types, so that the annual power cost is about the same. The continuously evacuated tank type rectifier has a high initial cost compared with the other types under discussion; the continuity of service of the tank type is less liable to interruption but should interruptions occur, they are likely to be of much longer duration. The provision of a duplicate rectifier as a standby is comparatively prohibitive in cost and the routine maintenance required by the tank type is greater and necessitates a higher degree of competence.

The comparison of the arc pool rectifier with the hot cathode rectifier would show that the initial cost of a simple rectifier is about the same in both cases, but that provision for sufficient spare equipment to insure continuity of programme shows a balance in favour of the hot cathode type.

Of the three types it may be said that the hot cathode rectifier shows promise of the greatest development since it is of comparatively recent origin. The trend of development will be mainly towards more powerful valves operating at higher inverse voltages. These features, combined with long life, will largely remove the chief disadvantage of valve renewals.

The Automatic Radio Compass and Its Applications to Aerial Navigation

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SUMMARY: *This article discusses the general principles of radio compasses; it describes the R.C. 5 Radio Compass and applications to aerial navigation. Comparison is made with other methods of navigation by radio, and applications of the radio compass in France and other countries are indicated.*

TEN years ago initial efforts were made to develop a radio compass system, then called "Hertzian compass," in which the angles indicating the position of a radio transmitter appeared automatically on a graduated scale, similar to the scale of an ordinary magnetic compass. Two years later, more complete studies were undertaken and rough models and testing apparatus were constructed. A first working model was then made and the essential principles established.

The apparatus described in this article is, therefore, the outcome of an old idea that had been developed over a period of several years. This idea had previously found practical application and was taken over to suit the needs of aircraft.

Thanks to the collaboration of the French Air Ministry, it was possible to make trial installations which were given exhaustive tests and which proved that the conception of the apparatus was sound. As a result, commercial production was commenced.

General Principles of Radio Compasses

The essential aim of a radio compass is to indicate the direction of a radio station and, fixed on board an airplane, it indicates the direction of a station by showing the angle made by the direction of this station with the airplane's axis.

An automatic and unbroken visual indication of the direction of a radio station with respect to an airplane has numerous advantages in navigation. By eliminating manual operation, navigation is made simpler and the chances of error, due to non-automatic and thereby intermittent indication, are reduced.

Under normal conditions, natural landmarks, villages, houses, or other prominent indications are often sufficient for navigation, the necessary information being transmitted to the human eyes by light waves. The automatic radio compass with its continuous visual indication of the position of a distant and unseen radio transmitter in effect increases in a simple way this visible horizon of the pilot.

We find in nature a similar extension of the horizon. Naturalists think that carrier pigeons and migrating birds navigate by using waves of a nature and in a manner unknown to us.

The radio compass has other applications which will be indicated hereinafter.

Description of the R.C. 5 Radio Compass

Principles. Le Matériel Téléphonique, Paris, has constructed a radio compass indicating the direction of a transmitter on a dial graduated in degrees completely around the circle. So far as is known, radio compasses built subsequently by others indicate merely the deviation of the airplane from its proper direction: if the plane be headed towards the left, the needle indicates "left"; if the plane be headed towards the right, the needle indicates "right," but no indication is given to the pilot as to how many degrees the plane has turned.

The radio compass herein described is, in fact, an automatic radio goniometer: it indicates the direction of chosen transmitters which may be situated all around the plane. More varied applications are thus possible than in the case of an instrument showing only the direction to the left or to the right of the axis of the airplane.

The apparatus is based on the following prin-

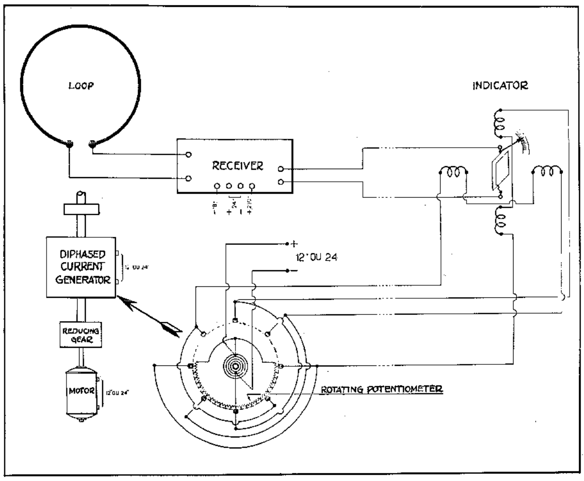


Fig. 1—Schematic Layout of Equipment.

ciple: a receiving loop aerial turning regularly around a vertical axis permits maximum reception every time that the plane of the loop passes in the direction of the transmitter. If the loop turns regularly at a certain speed, a certain number of maxima and minima of receptions per second can therefore be observed in a receiver tuned on a transmitter.

A rotating speed of five revolutions per second has been chosen. Maxima and minima of receptions, therefore, take place at the rate of ten a second.

The phase of these maxima and minima, i.e., the moment at which they occur in connection with a given origin, depends on the direction of the transmitter in relation to the axis taken as origin. If the loop turns regularly, these maxima always appear when the plane of the loop points in the direction of the transmitter. If the location of the transmitter changes in relation to the radio compass, the minima and maxima phases also change. This changing of phases is utilised in the apparatus to obtain the automatic indication.

The high frequency waves received in the loop pass through amplifier, detector, and low frequency amplifier stages in the receiver. In the output stage a variable current, representing the maxima and minima of reception, with phases identical to the phases of the wave received, is thus obtained. To obtain the measurement of phase in the indicating instrument, it is necessary to adopt a determined origin. This origin is obtained by placing on the rotating axis of the loop a diphased current generator, the phase of which is constant in relation to the revolutions of the rotating loop.

The variable current obtained at the output stage of the receiver, representing the maxima and minima of reception caused by the rotation of the loop, and the diphased currents from the generator are fed into a special, improved phasemeter. The diphased current creates a rotating field in a magnetic stator, comparable to the stator of a synchronous motor. This field rotates at a speed double the speed of the loop. The variable current from the receiver actuates an armature carrying a pointer associated with a dial. In this armature, therefore, an a-c. current is produced by the rotation of the receiving loop and, in the stator, a fixed phase rotating field by the diphased current generator. Thus the magnetic reactions of one flux on the other give a definite position to the armature, which sets itself perpendicularly to the flux when the current going through it is maximum, thereby indicating the phase looked for and, as will be evident later, the direction of the transmitter.

General Layout. Fig. 1 shows a schematic layout of the equipment. As indicated, the receiving loop is connected to a detector-amplifier receiver. The variable d-c. current, proportional to the signal, passes through the armature of the indicator. To simplify the diagram, the entire indicator dial has not been reproduced but merely the needle and a portion of the dial. In reality the needle is fixed and the entire scale rotates.

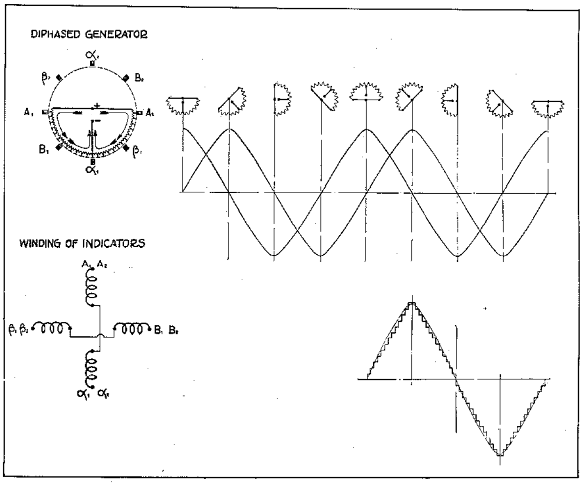


Fig. 2.

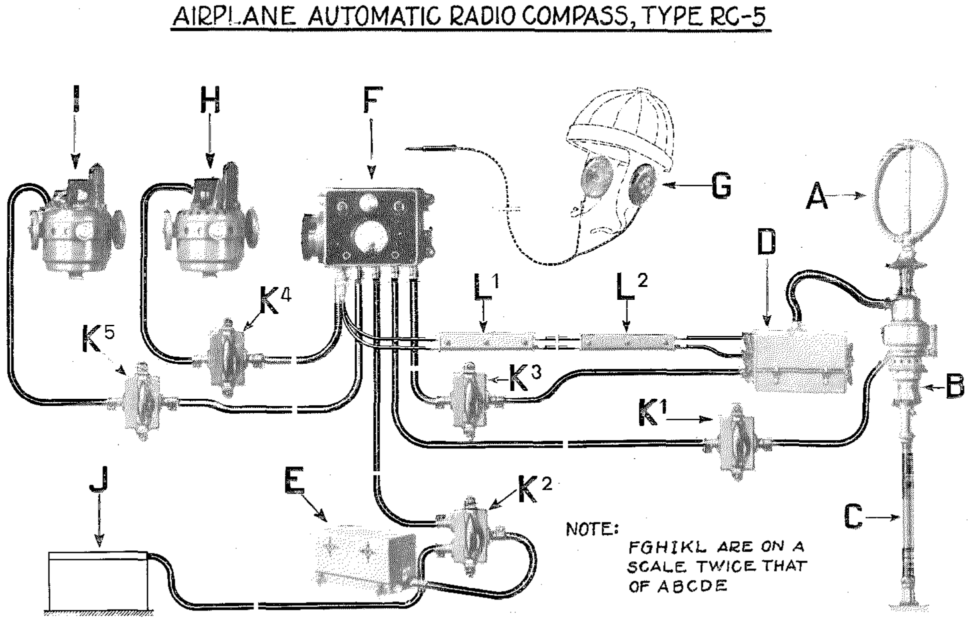

AIRPLANE AUTOMATIC RADIO COMPASS, TYPE RC-5
I
H
F
G
A
D
L1
L2
K4
K5
K3
B
K1
J
E
K2
C
NOTE:
FGHIKL ARE ON A SCALE TWICE THAT OF ABCDE

Fig. 3—Airplane Automatic Radio Compass, Type R.C. 5.

The diphased current generator, reduction gear, and the motor for driving the loop at constant speed also are shown.

The diphased current generator consists of a revolving potentiometer, fed by d-c. current, rotating regularly between fixed brushes. These brushes represent alternately opposite points of maximum positive or negative potential, and pass through all intermediate values in such a way that the result is the production on these brushes of an angular potential waveform which is rendered sinusoidal by the inductance of the stator of the indicating apparatus. Accordingly, an indication can be obtained at any distance, as only one simple electric link between the indicator and the other parts of the equipment is employed.

The potentiometer is neither continuous nor circular, but consists only of half a circumference since there are two maxima and two minima for each revolution of the receiving aerial, i.e., two periods of the variable current at the output-stage of the receiver for each one revolution of the loop. In order to synchronise the diphased currents with the variable current at the output-stage of the receiver, it is necessary that they should have the same frequency as the variable current. It is, therefore, necessary to double the rotation speed of the rotating magnetic field by doubling the frequency of the diphased currents relatively to the rotating frequency of the loop. When the loop rotates five times per second, the frequency of the output current of the receiver is 10 periods per second. The diphased current generator rotating at five revolutions per second also produces a current of 10 periods per second, because its current is collected on a half circumference, and because the number of brushes is eight, the brushes being fitted at 180° and commoned in pairs. The current reversals are twice as great as would be the case with four brushes and one complete circular potentiometer.

The brushes, bearing on brass segments, are connected to a resistance. There is thus formed on the segments a potential which may be represented by the lower curve of Fig. 2. This curve is simply due to the passing of the brushes from one segment to the other. The continuous line represents the nearly-sinusoidal current obtained when applying to a large inductance a tension of the above form and, in this case, to the stator of the indicator.

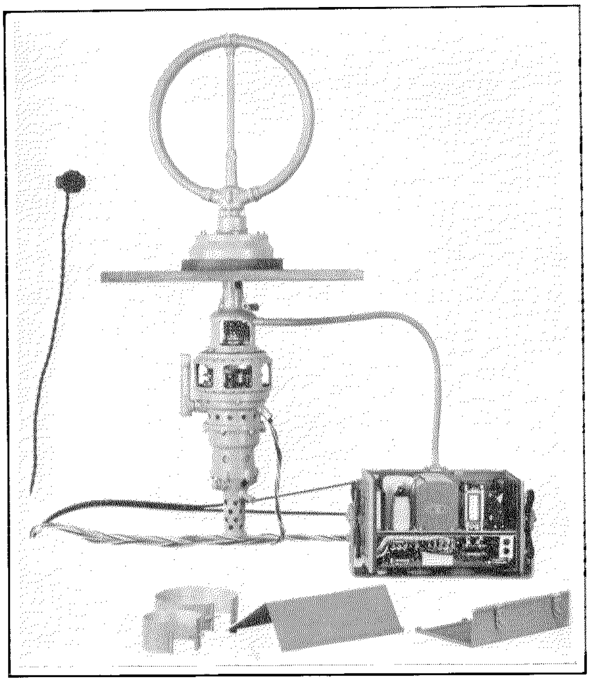


Fig. 4—Loops and Receiver with Covers Removed.

The upper part of Fig. 2 shows the diagrams of the diphased currents in the successive positions of the resistances.

In the indicators, the magnetic reaction of one flux on the other causes the armature and dial to take up a steady position and thus to indicate the direction of the transmitter in connection with a predetermined origin. This origin is simply the setting which exists between the diphased generator and the receiving loop: by modifying this setting by mechanical means, the origin can be modified as desired and the indicators can be made to show the zero angle when the airplane is heading towards the transmitter.

The indicator not only utilises the current maxima to show the direction, but it also entirely integrates the variable current due to the signal. Therefore, the sensitivity is very high and the stabilising of the indicator is proportional to sin α (α being the angle through which the armature might be artificially pulled out of position).

This integration of the effects of the variable current is due to inertia of the armature. However, the inertia has been so limited that the armature vibrates at 10 periods per second on about $\frac{1}{4}$ of a degree, which considerably lowers the initial friction of the pivots and has the added advantage of allowing the observer immediately to detect a possible "dead" receiver or any other fault which may occur.

Description. Fig. 3 gives a general view of the equipment. The indicating apparatus and the control units are shown on a scale double that of the loop. "*A*" represents the receiving loop. Beneath it, the high frequency collector, which gathers the currents generated in the loop and, also, the high frequency transmission line leading to the receiver are mounted. "*B*" represents the small generator, the reducing gear, and the motor operating the receiving loop.

The receiver *D* and the rotating loop *A* are entirely remote-controlled by a small control unit, comprising simply the mechanical remote tuning of the receiver, a volume control to adjust the signal intensity, and a main "on" and "off" switch which, in a third position, starts the rotation of the loop.

Two indicators can be utilised. One is called "navigator's indicator" and the other, "pilot's indicator." In the first, the indication is read on a movable dial graduated in 360° and moving in connection with a fixed pointer. In the second, the indication is limited to plus or minus 15°.

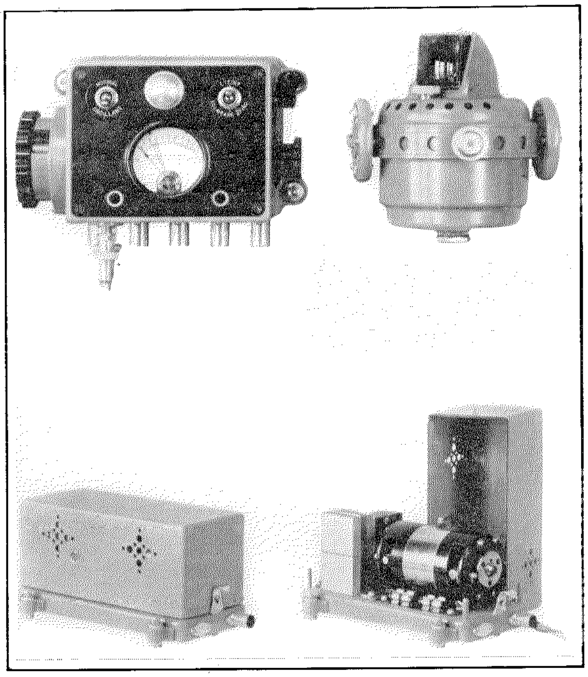


Fig. 5—Control Unit with "Navigator Type" Indicator (Upper portion of illustration); Converter (Lower portion of illustration).

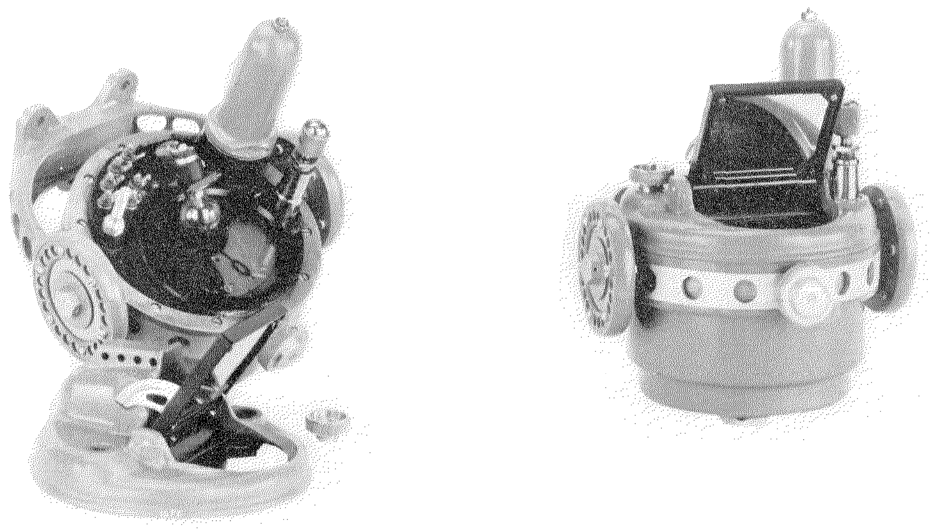


Fig. 6—"Pilot Type" Indicator.

The first is called "navigator's indicator" because it allows any of the crew of the airplane taking bearings to determine the position of the plane in relation to any given transmitter located around the plane.

The second is specially limited and designed for flying toward any given transmitter, and especially concerns the pilot. It represents an important advantage over the so-called "homing" systems, and permits correction for drift.

By means of this indicator the pilot can modify the reference axis by ±15° in such a way that by altering his pointer the same amount of degrees as the angle of drift he can still steer with his indicator on zero and thus fly a great circle course directly to the transmitting station. This would not be possible with a so-called "homing" device. In fact, for this facility, it is necessary that the indicating apparatus itself indicate angles and that it be not limited to indicating a movement to the left or to the right.

In Fig. 3, E represents the converter for the anode high tension. This converter is fed by the storage battery J.

The units L_1 and L_2 permit rapid disconnection of the remote control, and the junction boxes K_1, K_2, etc., allow very rapid replacement of any part of the apparatus by a standard, identical part.

Fig. 4 shows in a more detailed manner the receiving loop of .3 metre diameter which, to the best of the writer's knowledge, is the smallest of its kind. Its aero-dynamic drag in a wind of 170 km. per hour is about 3 kg., and this drag only increases by 100 or 200 grammes when the loop is rotating.

The receiver is shock-proof mounted.

In Fig. 5 is shown the control unit with the remote control tuning dial on the left, and the milliammeter showing the current generated by the signal at the centre; also the navigator's type indicator, which is movable in all directions to facilitate reading of bearings. For the same reason, the position of the magnifying glass also can be changed.

The lower part of Fig. 5 shows the small rotary HT converter for the receiver. The radio compass is entirely fed by the airplane's battery, 24 or 12 volts, and will operate correctly with a current variation of ±15%.

Fig. 6 shows the "pilot's indicator" permitting correction for drift. This indicator is constructed especially to make readings for the pilot as simple as possible and differs from the navigator's

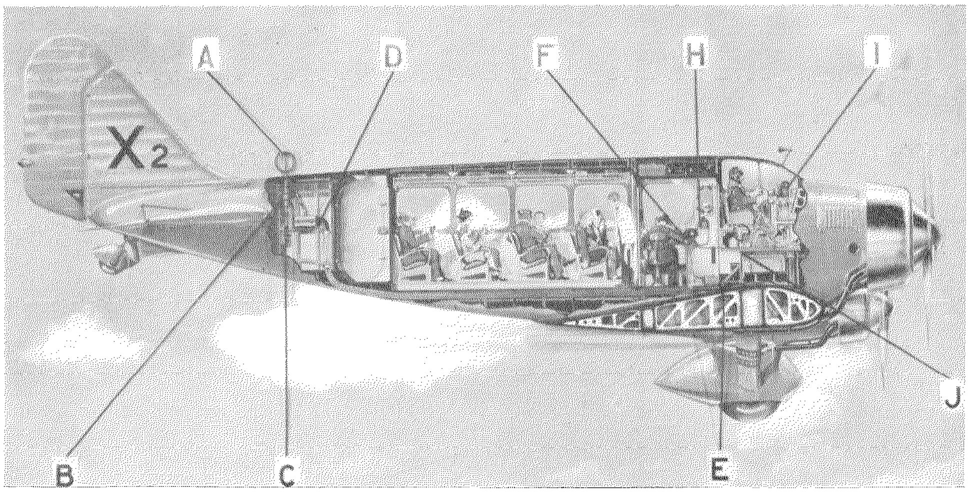


Fig. 7—Installation of R.C. 5 Radio Compass on an Airliner.

indicator with its 360° scale. When piloting, it is difficult to maintain an indicating graduated dial on a predetermined value and pilots prefer to keep a needle in one position without figures, even if they have to do the setting by other means. It is this principle which is used here.

The reading is made directly by means of a needle associated with green and red sectors, the dead centre indicating the plane's position when flying towards the transmitter. These sectors can be moved ±15° by means of a control knob and allow correction for drift. The position of the needle can be read either directly, or by means of a mirror in case the apparatus is placed high enough on the dashboard.

The radio compass does not itself indicate the "sense" of direction. It will be shown later that there are several ways of eliminating this 180° ambiguity.

The total weight of the apparatus without the wiring is 22 kg. Depending on the size and type of the airplane, a few kilogrammes must be added for wiring.

Applications to Aircraft Navigation

Installation on board airplanes gives rise to a certain number of problems. The first is the deviation of the waves due to the metal parts of the airplane or to the closed circuits formed by them. These deviations are constant and cause errors in bearings which may be as much as ±10° or 15°. Nevertheless, by choosing the proper location for the loop it is possible to reduce these deviations to a small figure, sometimes even to zero.

Let us take as an example the case of an all metal high wing monoplane: At certain positions on wings or fuselage, the refractions of the wireless waves will be at a minimum. Therefore, it is essential to install the loop-aerial at one of these positions, provided, of course, that the position of the receiver inside the plane will permit. With the exception of the loop-aerial and receiver, the relative positions of which are governed by the fixed length of the transmission line connecting the two, all other parts of the equipment can be installed at the most suitable places.

In the case of low wing airplanes, deviations cannot always be avoided. However, as the deviation is nil at right angles to either the longitudinal or athwartship axis of the plane and rises to its maximum only at a 45° angle to these axes, this constant error can be corrected by reference to a very simple correction curve.

Fig. 7 gives an example of an installation, using the same reference letters for the various parts as in Fig. 3. It shows a case where the frame and the receiver are installed in the tail of the airplane. Sometimes there is not much room to spare, even for small apparatus, in the pilot's cockpit, and this is especially true in transport airplanes where the pilots are in front and the radio operator directly behind them.

The control of the equipment is solely effected by the remote control unit, and the indication is given at the most suitable points in front of pilot and navigator by means of their respective indicators.

Accuracy. The guaranteed accuracy of the apparatus is ±2° for a distance of about 500 km. from a 300 watt transmitter. The receiver is extremely sensitive and, in most cases, this sensitivity is not fully employed. In fact, from the point of view of accuracy, it is difficult in an

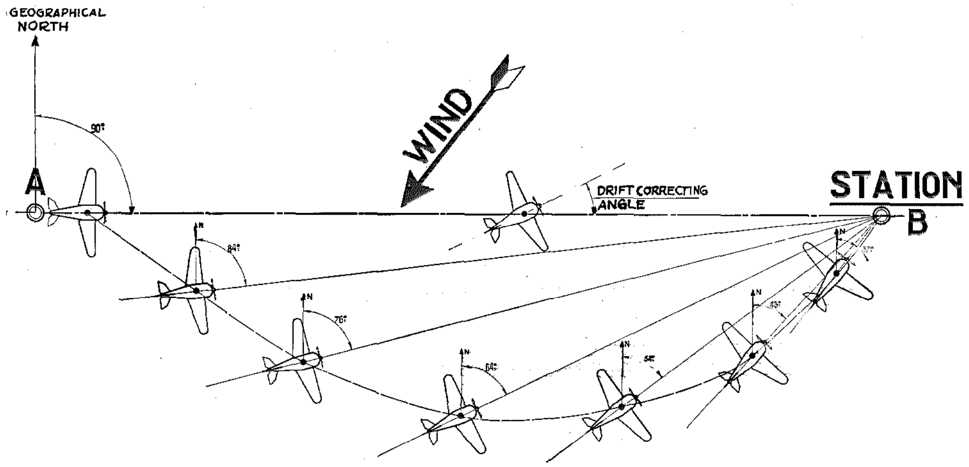


Fig. 8—Exaggerated Curve Illustrating Drift Due to Wind.

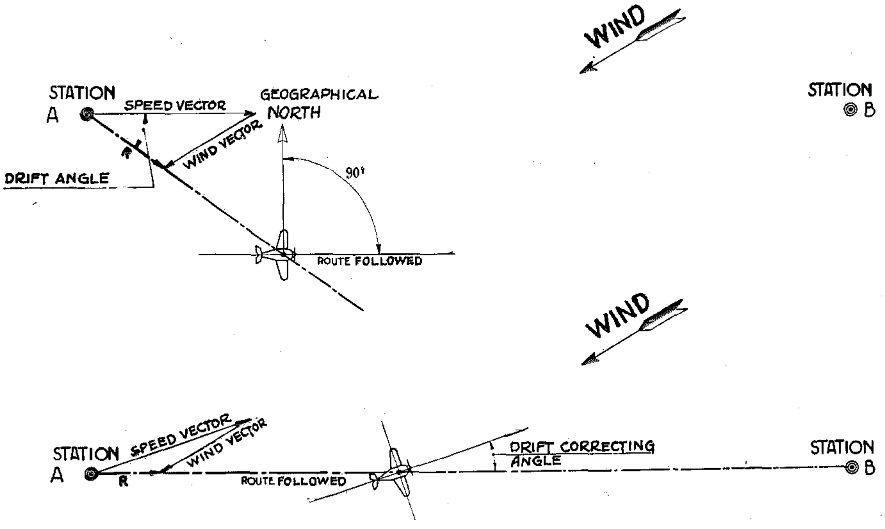


Fig. 9—Deviation Research with a Radio Compass.

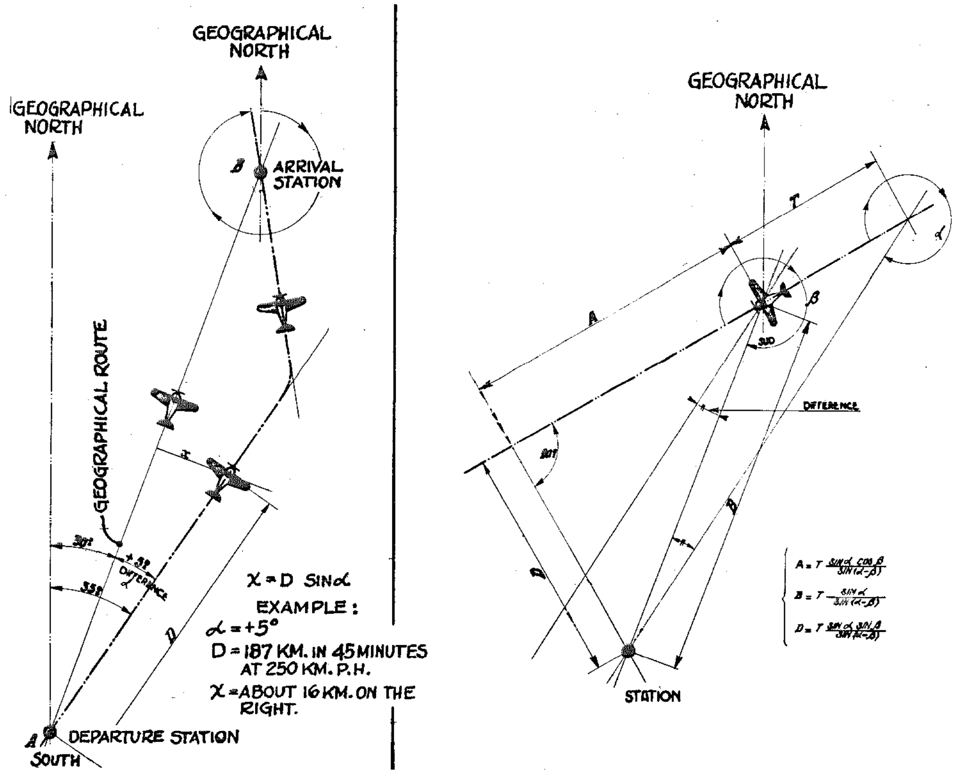


Fig. 10—Illustrating Methods of Correcting for Drift.

airplane to navigate within 1° to 2° and, therefore, this figure is fully satisfactory for aerial navigation.

Due to the well-known errors in magnetic compasses, such as the northern turning error, etc., it is difficult to keep an airplane on a steady course by means of a magnetic compass alone. The great stability of the R.C. 5 indicators, therefore, considerably facilitates the keeping of a correct course. In this connection it should be noted that the indicators allow for a plane, an inclination of about 30° without producing a fault greater than 1°.

The above reference is not meant to be a criticism of the utilisation of the magnetic compass which, so far, is an indispensable apparatus, but it is desired to show the advantages offered by navigating directly with the indications of the radio compass. Furthermore, the utilisation of the magnetic compass can always be combined with that of the radio compass.

Interference. As indications are given automatically, an important point is the question of interfering transmitters. When using the equipment on broadcast transmitters, interference is not to be feared, due to allocation of wavelengths. When utilising weaker transmitters, no difficulty has ever arisen, owing to the selectivity of the receiver.

Very exhaustive experiments have been made on this point. Two stations of the same power were used, situated 90° one from the other, which is the worst case as regards interference: the frequency of one station was varied in order to note when it would start and when it would stop interfering with reception of the station having a fixed frequency.

A difference of 1 kc. between the frequencies of the transmitters is sufficient to give a correct indication on the fixed frequency transmitter. However, interference, if any, can both be seen and heard, and thus the operator is warned against the use of such indications.

The range of powerful broadcasting stations is, of course, much greater than that indicated for the small power stations. Through a station like Radio-Paris (60 kw.), it is possible to work the R.C. 5 radio compass as far as 2,000 km., and even more, at sea. In fact, ranges at sea are much greater for a given power than on land.

Night Effect. Like all radio direction finders, the apparatus can be affected by the "night effect" produced by the fact that at night the radio direction finder receives two or more waves: the direct wave following the curvature of the earth, and the indirect waves being reflected by the ionosphere. On land this error starts at about 70 to 100 km. from transmitters employing ordinary antennae; at sea, the error starts at greater distances: 200 or 300 km.

In order to reduce this error on land, numerous means of transmission can be employed. Transmitters utilising an aerial strictly vertical or an "anti-fading" antenna, considerably reduce these errors and the operating range increases by 200 km., which is sufficient in most cases where the radio compass is utilised. It is possible to navigate by utilising stations situated one after the other without having to take, when starting, the most distant station.

The question is often asked as to which stations can be utilised:

First, the numerous broadcasting stations which, situated near big cities, form a close net of Hertzian beacons for navigation over great distances.

Second, all radio beacons of any transmission system, directive or not, for air or sea navigation. The radio compass will indicate their direction, the same as in the case of an ordinary transmitter.

Airport stations can also be utilised. On receiving a call from an airplane, they can transmit for some ten seconds at regular periods to direct the airplane towards the airport.

If necessary, further non-directive transmitters can be installed on regular air routes to serve as beacons.

In this connection, it should be stated that modern broadcasting stations utilise the so-called "anti-fading" antennae, which also avoid the night error.

The pilot and the navigator must have a small map of their flying area, giving them information on the transmitters that can be utilised, as well as their range without night error, their power, and their normal wavelengths.

Navigation with the Radio Compass

The easiest method of navigating with the radio compass consists in tuning the radio compass on a given station situated at the aerodrome of destination, and then to operate in such a way that the indicators show the angle as 0°. In this way, the airplane always flies in the direction of the station and, if the wind is nil, it flies in this direction along a great circle. In most cases when drifting by wind, a curve is traced that pilots and navigators call the "drift-curve."

Fig. 8 illustrates such a curve. An airplane equipped with a radio compass always has its axis directed towards station *B*, but the wind causes deviations from the course and should be allowed for. On such a curve, it is easily seen that the angle indicated by the magnetic compass, i.e., the magnetic course followed by the airplane, constantly changes; and, therefore, the true course of the plane also constantly varies. It should be noted that this curve is exaggerated

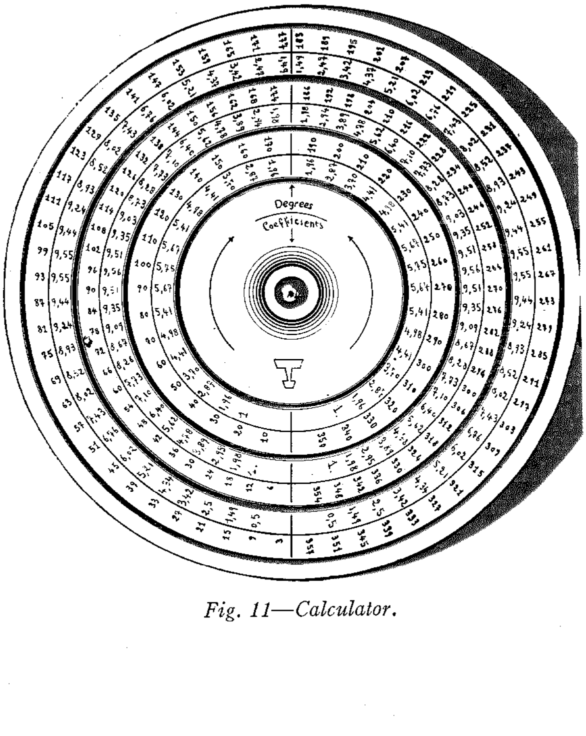


Fig. 11—Calculator.

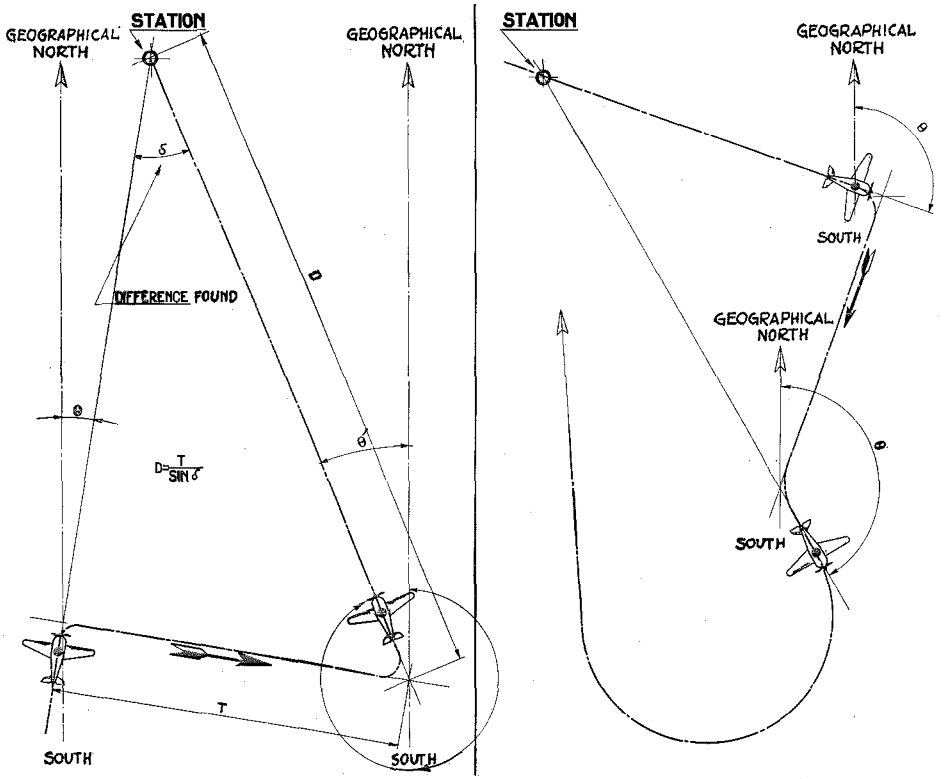


Fig. 12—Illustrating Methods of Correction for 180° Ambiguity.

for illustration purposes. The true course varies from 90° to 54° and in the end the airplane reaches the station in the wind's direction on a 37° true course. If it reaches the transmitter's aerial, it passes exactly over this antenna facing into the wind. Indication is given to the pilot by the rise of the volume of reception; and, after having passed by a 180° change in indication, the pilot is enabled to read the wind direction from his magnetic compass.

But it is possible to fly along a straight course between two points by allowing for the drift. If, after flying for a few minutes towards the station, the pilot finds that the magnetic compass angle is getting smaller, it means that the plane is drifting towards the right and that the wind is blowing from the left. Then the pilot must adjust his course with the aid of the R.C. 5 radio compass. By a method of trial and error, the correct drift angle can be found and thus the airplane can be maintained on a great circle course towards the station. It is the course which gives a constant reading of the magnetic compass with a constant indication of the R.C. 5 radio compass (see Fig. 9). Thus, when the correct drift angle has been determined, the pilot flies with the magnetic compass and radio compass readings corrected for drift.

It should be noted that when a pilot possessing an R.C. 5 radio compass leaves a transmitter station, he can rapidly determine his drift angle, since it is only necessary for him to fly on a certain magnetic course and to measure the angle at which he sees the station on the radio compass. This angle is the angle of drift with reference to the point of departure. By this means the angle of drift is determined, but it must be remembered that the angle of correction for drift is not the same and can only be determined by applying the previously mentioned process.

The methods just outlined were described in 1927 in "*O'Onde Électrique*," and apparently they were new at that time.

Referring to the left portion of Fig. 10 assume that, from the point *A*, the pilot wishes to maintain a course 30° from the geographic north. He notes after a certain time that, with a 0° bearing of his radio compass on transmitter *A*, his magnetic compass indicates a difference of 5°; then he no longer flies on a 30° course, but on a 35° course. This difference enables him to determine the approximate distance he is off his course. If the angular difference had been negative, the pilot would have known that he was on the left of his course. The same process can be utilised with station *B*, but in this case a positive difference indicates a deviation to the left, and vice versa.

The right portion of Fig. 10 represents a general case where there are no stations either at the point of departure or destination, but where there is a suitable station situated on the side. Formulae for determining the distance of the plane from this station are indicated in the illustration.

Obviously, neither the pilot nor the navigator would have the time for applying these formulae on board an airplane. Simple course and distance calculators which can be read very quickly have been made. Given, on the one hand, the distance already traveled from T_1 (the product of speed by time) in a direction known by the pilot between the two points T_1 and T_2; and, on the other hand, the difference between two bearings taken on the stations T_1 and T_2, the pilot can determine the distance from T_2. Information of this character is, of course, highly useful and is readily obtainable by reference to a regular broadcasting station in cases where a transmitter is not available at the points of departure or arrival. If a low power station is available at the point of destination, it can, of course, be used during the latter part of the journey.

Fig. 11 shows the calculator in question. The coefficients apply regardless of whether the stations are on the left or right.

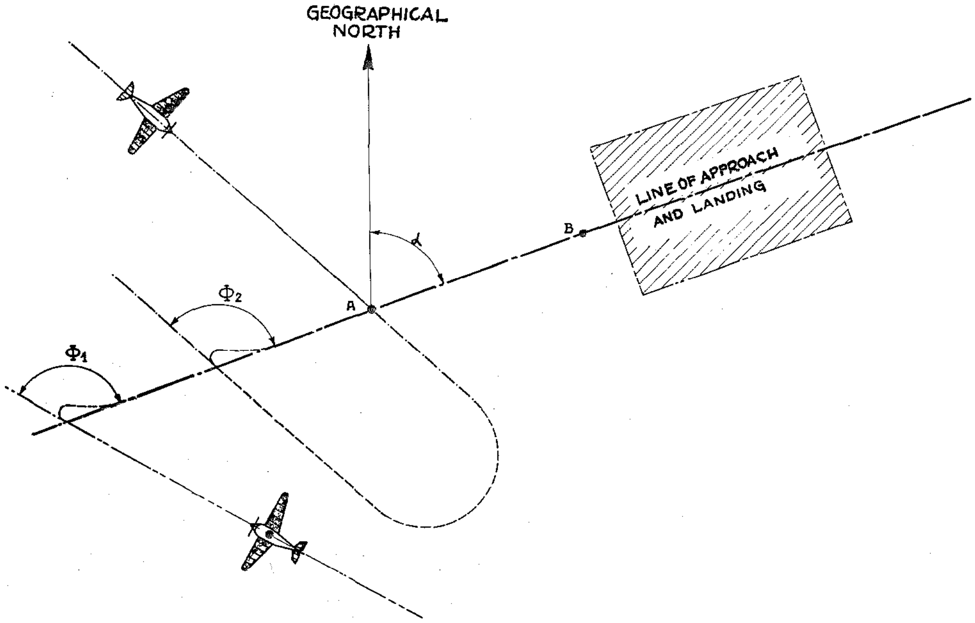


Fig. 13—Illustrating Application to Landing.

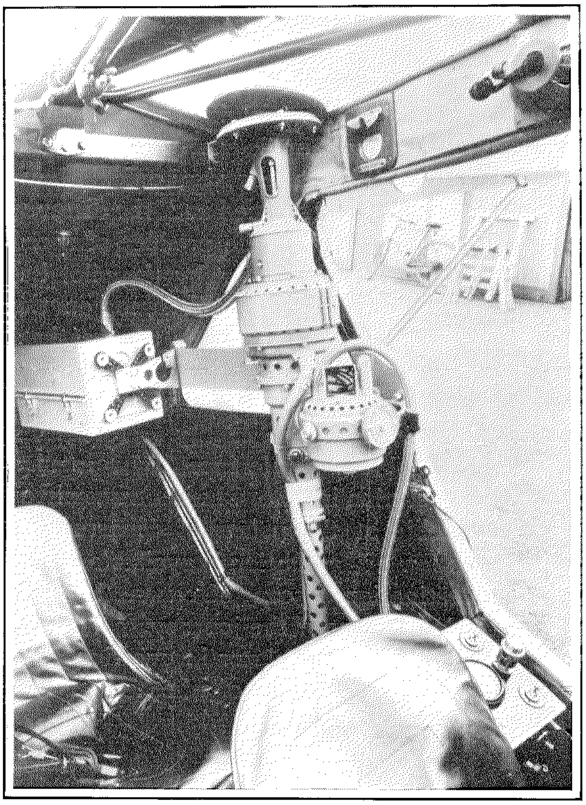


Fig 14—Experimental Installation of the R.C. 5 Radio Compass on a Small Airplane.

Suppose that the plane is going in a certain direction and that it keeps a steady course. The pilot looks at the radio compass indications and, for example, reads 30°, at the same time noting the exact time. After an interval of 5 minutes at an air-speed of 300 km. per hour, i.e., after flying 25 km., he reads 36°. On his "calculator" he finds the coefficient 4.78 for 36°, and a simple multiplication of this coefficient by the distance he has just flown will give him the distance at which he is from the station, i.e., about 120 km.

180° Ambiguity. The left-hand diagram in Fig. 10 shows the correct means of obtaining sense, i.e., of ascertaining whether the transmitter is ahead or astern. When flying a fair distance away from the transmitter the possibility of not knowing the location of the transmitter is small. However, near the transmitter, it might be difficult to locate the exact position (180° fault).

There are two main methods of coping with this situation: (1) there is the intensity variation of the received wave, which of course increases or decreases according to the direction of flight to or from the transmitter; (2) a 90° deviation from the course flown, and, after a few minutes, again turning the radio compass to 0°. A decrease of the magnetic reading indicates that he is flying towards the station, whereas an increase points to the fact that he is flying away (see Fig. 12).

The larger the difference in these magnetic courses, the nearer the airplane is to the transmitter.

Applications to Landing

The fact that, with a radio compass, the airplane passes just over the station towards which it has been flying leads to the possibility of using the R.C. 5 for landing under conditions of very low visibility. This has been demonstrated by numerous tests and was accomplished by methods indicated in Fig. 13.

With the radio compass the exact location of a transmitter can be found; thus this transmitter becomes a marker beacon.

Two different examples of landing with the aid of the R.C. 5 radio compass are described hereinafter (see Fig. 13).

First, it should be noted that the airplane is fitted with a sensitive altimeter which, before the landing, must be adjusted to the actual atmospheric pressure of the aerodrome. This information is transmitted to the airplane in a normal radio message (QFE). With such an instrument the pilot knows his height within 10 metres and this should be sufficient in most cases, inasmuch as, in practice, vertical visibility does not ordinarily fall below this figure.

Second, a directional gyro is of great assistance to the pilot during the last stages of the approach.

Further, it is assumed here that *A* and *B* represent two transmitters lying in the line of approach to the aerodrome. *B* only needs to be a transmitter of very small power.

It is, of course, necessary for the pilot to know the direction of the correct line of approach (in Fig. 13 this is approximately 70°).

Example 1. When the pilot, who has been flying towards transmitter *A* by means of the R.C. 5 radio compass, gets near *A* and the aerodrome (for instance, 10 to 20 km.), he deliberately flies off this course and continues on a certain compass course. As shown in the diagram, this course makes an angle Φ_1 with the line of approach. Φ_1 can be readily computed from the known course bearing and the known direction of the line of approach. As the pilot proceeds along this altered course, the direction of the R.C. 5 continuously changes. When the R.C. 5 indication equals the previously computed angle Φ_1 the pilot knows that he is in the line of approach. He then only has to turn his machine till the R.C. 5 reads 0° to approach the aerodrome in the correct direction. He will now automatically pass over *A* and the moment he is overhead is indicated by the R.C. 5. He then starts losing height and tunes his R.C. 5 on *B*, keeping the same compass course and directional gyro indication; the R.C. 5 should still show 0°. In passing over *B* he should be low enough to be able to effect a landing at the aerodrome. This height depends on the distance of *B* from the flying field. The position of *B*, however, should normally be such that, for a good landing, the airplane should pass over *B* at a height of approximately 30 metres.

Example 2. If it is difficult to decide at what distance before *A* to discontinue the 0° reading of the R.C. 5 (as described above), the pilot may approach *A* continuously till he actually passes overhead. The R.C. 5 will thus give him a "fix." He is not, however, flying in the correct direction of approach. But the R.C. 5 will again prove indispensable: after passing over *A* he continues on the same course, R.C. 5 again reading 0° for a certain time, for instance, 3 minutes. Then the pilot makes a wide turn through approximately 180°, turning away from the aerodrome. He flies back on a certain compass course, and then the procedure is as in Example 1.

Comparisons with Other Methods of Navigation by Radio

First, let us compare the radio compass with other direction finders used on airplanes. The radio compass gives automatically the indications that, with a direction finder, can only be secured by a skilled operator.

The trend is more and more towards automatic operation and, inasmuch as a direction

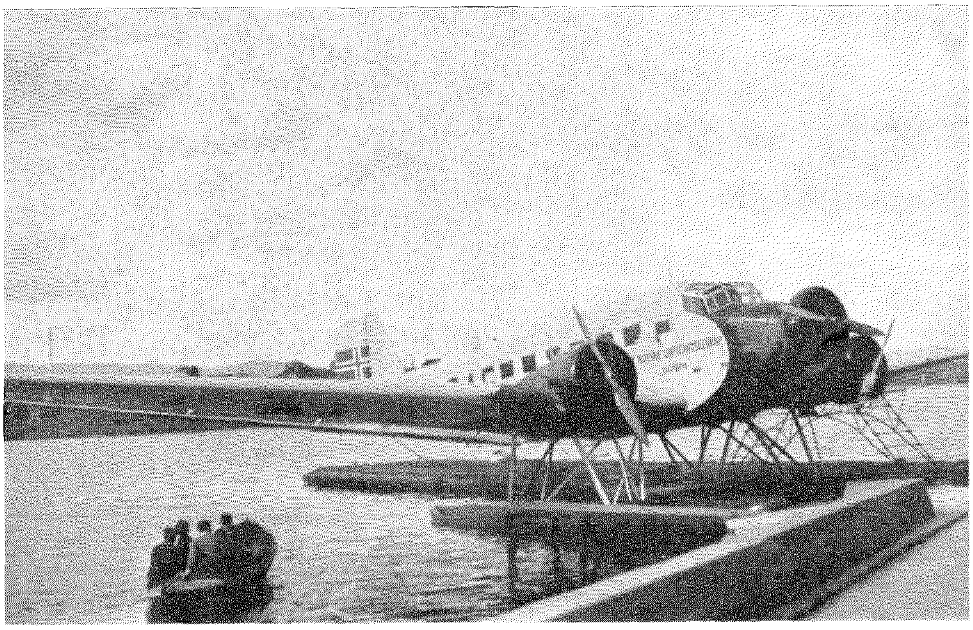


Fig. 15—Seaplane Equipped with the R.C. 5 Radio Compass.

finder does not operate automatically, the indications are that the radio compass will find increasing application in aerial navigation. In contrast with the radio compass, the direction finder makes it necessary for the radio operator to take bearings of the transmitter and pass them on to the pilot in order that the latter may make the necessary course adjustments. Further, course adjustments on the part of the pilot are not made by direct indication, but through the medium of another navigating instrument, either the magnetic compass or the directional gyro.

The correction, if made with the help of the magnetic compass, will always be 3° or 5° behind, thus making the course unsteady. When operations have to be rapid, the direction finder cannot be used and, for instance, cannot be used for landing or even for passing directly over marker beacons. Further, with an ordinary airplane direction finder, the operator must find the point of minimum reception, which is difficult to determine on board a plane on account of the engine noise, while, with the radio compass, the noise question is quite secondary since the indication is automatic and much more practical. With a radio compass the pilot navigates directly and, inasmuch as this instrument has less inertia than a magnetic compass, the course is held more accurately and with less effort.

Ground Direction Finders

If a comparison is made with ground direction finders, it is found that, in no case, can they render the same amount of service as the R.C. 5 radio compass. This does not mean that the ground direction finder is useless; on the contrary, it appears to the author to be of great assistance in checking the position of airplanes.

A single ground direction finder cannot furnish sufficient indications to numerous approaching planes to enable them to navigate safely under unfavorable conditions. At important aero-

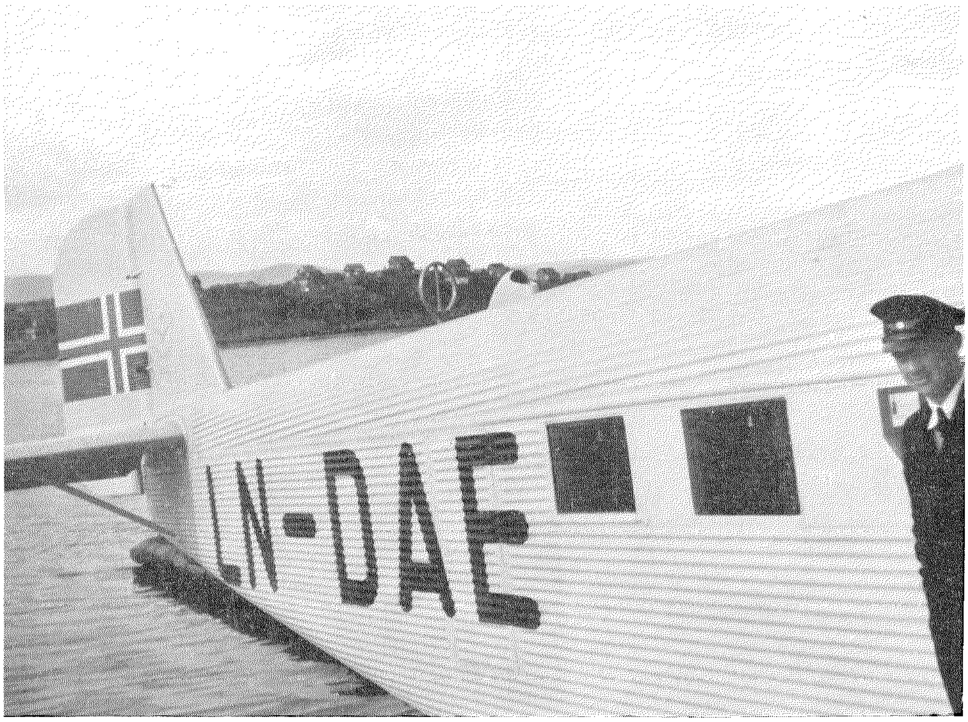


Fig. 16—Near View of the Loop of the R.C. 5 Radio Compass on the Seaplane Shown in Fig. 15.

dromes, where ground direction finders are ordinarily used, several planes asking for bearings (QDM) or for landing indications by means of the ZZ system, or both, during bad weather, quickly overload the ground direction finders and all demands cannot be answered. Several months ago, during a heavy fog in London, several airplanes had to return to their home aerodromes as they could not land, since the ground direction finder could not give the necessary indications to all of them. An R.C. 5 radio compass would have enabled them to navigate; and the utilisation of a landing system (as for example, a radio beacon and marker beacon system, or the R.C. 5 radio compass system following the principles above outlined) would have facilitated landing.

Radio Beacons. If we compare the radio compass to radio beacons on a definite route and, in general, to all systems in which directivity is given from a stationary transmitter, it is easy to see that the R.C. 5 radio compass offers more possibilities and, in addition, allows military airplanes to approach with great secrecy.

The radio beacon has the disadvantage of indicating to anybody the route leading to it, enemies as well as friends. Its advantage is that the plane is able to navigate on a well defined beam. But, with the radio compass, airplanes can also navigate easily on a beam. Simultaneous observation of a magnetic compass or of a directional gyro and of the R.C. 5 radio compass makes it easily possible to fly on a straight, great circle course towards the desired destination.

A limitation of the radio beacon is that it can indicate only one or two directions of navigation and all airplanes using it must follow the same route. An ordinary non-directional transmitter, however, constitutes a complete Hertzian beacon for radio compasses. An equivalent result could not be obtained with directional radio beacons without employing an infinite number. In actual practice there ought to be as many radio beacons as airways to be followed, the realization of which would certainly appear difficult.

The R.C. 5 radio compass, from this point of view, has many advantages for military purposes. In no case can it be accepted that a military plane experiencing navigational difficulties should have to ask indications from the ground. Such a demand might be useful information to an enemy. The military plane fitted with a radio compass can navigate without any assistance. It is even impossible to find out what station it is using for its navigation. This station may very well be a broadcasting station, serving as a radio beacon. Also, the transmitter may be changed frequently.

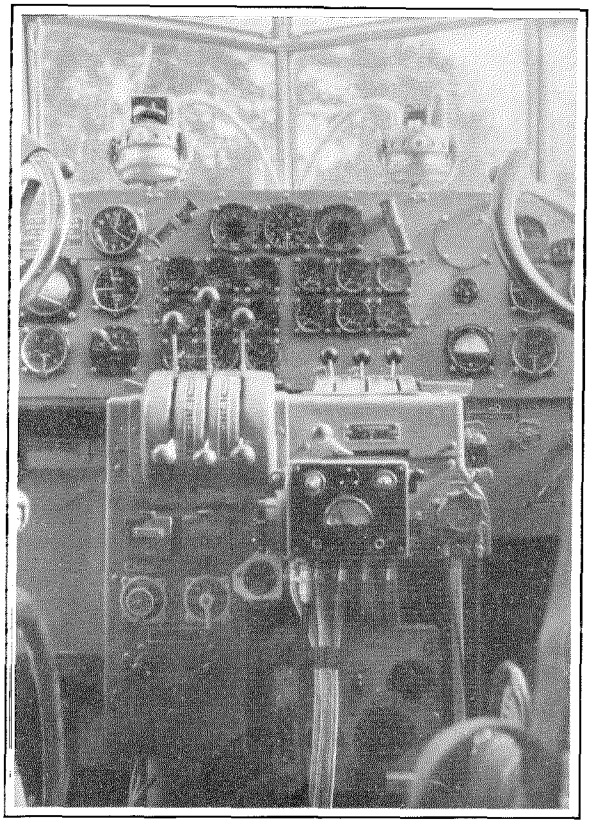


Fig. 17—Installation of Control Unit and Indicators of R.C. 5 Radio Compass in the Pilot Cabin of the Seaplane Shown in Fig. 15.

The radio compass can be utilised on powerful stations situated at a great distance, thus permitting navigation over several hundred kilometres. When desired, the pilot can abandon this station to pick up a weaker station, which cannot be heard at a few hundred km. distance, but which will permit the pilot to traverse the 50 or 100 km. to the transmitter and from there to the airport where he must land.

Radio Compass Installations in France and Other Countries

Experiments have been made on board a small plane (Fig. 14) and it will be seen that, despite the limited size of the cabin, the radio compass is not in the way. The loop assembly, the receiver, the control unit, and indicator are shown.

Figs. 15 and 16 show the relative size of the loop of the R.C. 5 radio compass compared with a seaplane of a Norwegian Air Line. As in Fig. 7, the loop is at the rear end of the fuselage and the whole equipment is remote-controlled from the pilot's cockpit.

Fig. 17 shows the pilot's cockpit of the same plane, where the pilot's indicator can be seen in the left-hand top corner of the illustration and the navigator's indicator on the right. As the radio operator sits between the two pilots he can easily operate the radio compass by the control unit shown in the centre of the cockpit. The operator only has to tune the receiver, by means of the control unit knob, on the desired station and read the bearing in the navigator-indicator, while the pilot reads the other indicator.

In France, both civil and military aviation authorities have submitted the radio compass to exhaustive tests and many airplanes have already been equipped with it. These installations are in daily use and have given such good results that additional planes will be similarly equipped in the near future. Installations are also being made in Norway, Spain, Czechoslovakia, and several other countries.

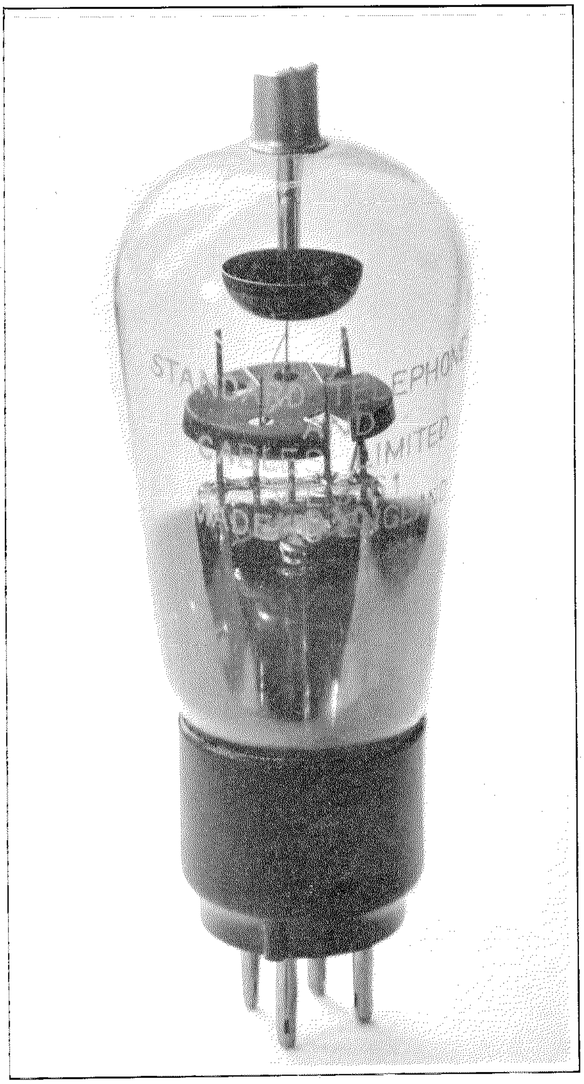
In some countries use is made of so-called radio compasses and considerable publicity has been given to such equipment. Practically all of these so-called radio compasses are in reality nothing more than "homing devices," the characteristics of which have been compared herein with the automatic radio compass. These "homing devices" should not be confused with the automatic radio compass which, so far as is known, is the only one of its kind now in existence.

Recent Telecommunication Developments of Interest

Television Rectifier. The accompanying illustration shows the new, small, high-voltage, low-current rectifier developed by Standard Telephones and Cables, Limited, London, for use in cathode ray oscillograph and television equipment.

This valve—the VLS61—is only slightly over five inches in height and two inches in diameter. In spite of its compactness, however, the design, which employs an internal shield over the filament leads, permits operation at high voltage without danger of flashover. It will deliver 3 milliamperes at 6,000 volts in a half-wave circuit.

The VLS61 represents one of the numerous steps required to reach the "corner" around which television is popularly supposed to be located.



• • •

Audibility—5 Miles. Standard Telephones and Cables, Limited, London, successfully completed its annual job of installing and operating the public address system at the Aldershot Tattoo. This installation, which is required to serve the hundred thousand spectators at this gigantic military pageant, is one of the largest temporary installations in the world.

The battery of loudspeakers, driven from a 300 watt amplifier, is easily audible at a distance of 5 miles. In addition to the main battery of loudspeakers, four portable units, comprising thirty-two smaller loudspeakers, were employed for community singing. The amplifier equipment employed forty-four Standard valves of eight different types.

All apparatus, including the 300 watt power amplifier, was in duplicate. The precautions extended to a battery-driven motor-generator power supply, in case of mains failure. One of the emergency amplifiers was brought into use when lightning struck one of the regular amplifiers. The audience was unaware of the incident and noticed no interruption, thanks to Standard Telephones and Cables' efficient operating staff and the carefully planned emergency provisions.

• • •

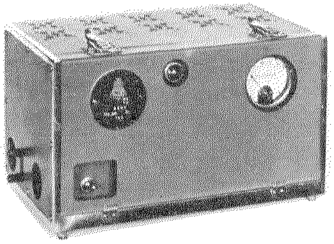
The Public Address Units shown in the illustrations represent new Le Matériel Téléphonique, Paris, developments. They include a 20 watt amplifier, a dynamic microphone preamplifier, and a carbon microphone adaptation box.

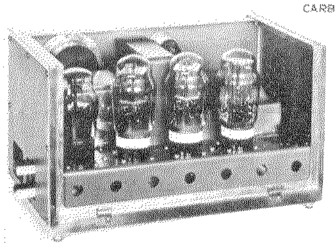
The 3223 amplifier will deliver 14 watts with 5% harmonics, or 20 watts with 10%. It has a fixed gain of 72 db., and a remarkably flat frequency characteristic from 40 to 20,000 cycles with a variation of only 1 db.

It is completely a-c. operated and portable. It may be used with dynamic microphones in conjunction with the preamplifier, or with carbon button microphones, gramophone pickup, or programme line when used with the adaptation box.

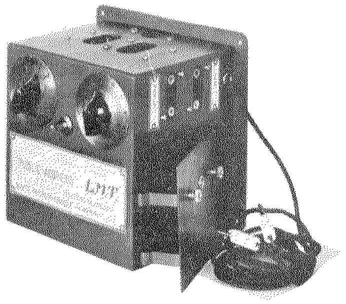
The preamplifier is designed for use with the 3223 amplifier and, in conjunction with it, supplies an overall gain of approximately 115 db. The switching arrangements permit the selection of either of two dynamic microphones, or the mixing of both in the required proportions. All power supply is obtained from the 3223 amplifier.

The adaptation box provides the inputs and the switching controls for a single or double-button carbon microphone, a gramophone pick-up, and a programme line. These separate inputs may be individually selected or mixed as desired. Space is provided for carrying a small 4.5 volt microphone current battery. If desired, the units may be interconnected so that the microphone battery switch simultaneously controls the mains supply for the 3223 amplifier.

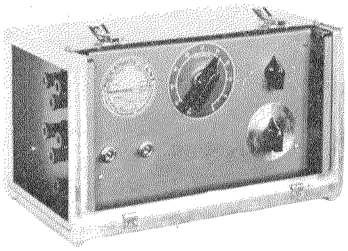


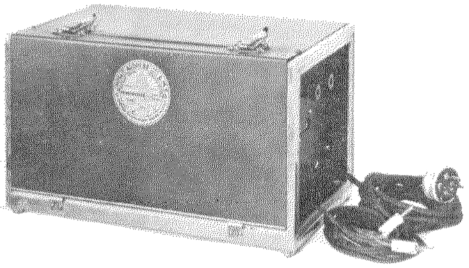


14 - 23 WATT. Nº 3223 AMPLIFIER



CARBON MICROPHONE ADAPTATION BOX





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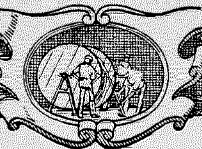

ELECTRICAL COMMUNICATION

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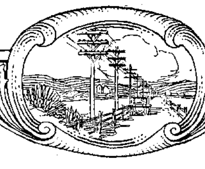

ELECTRICAL COMMUNICATION

A Journal of Progress in the Telephone, Telegraph and Radio Art

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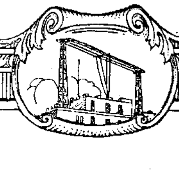

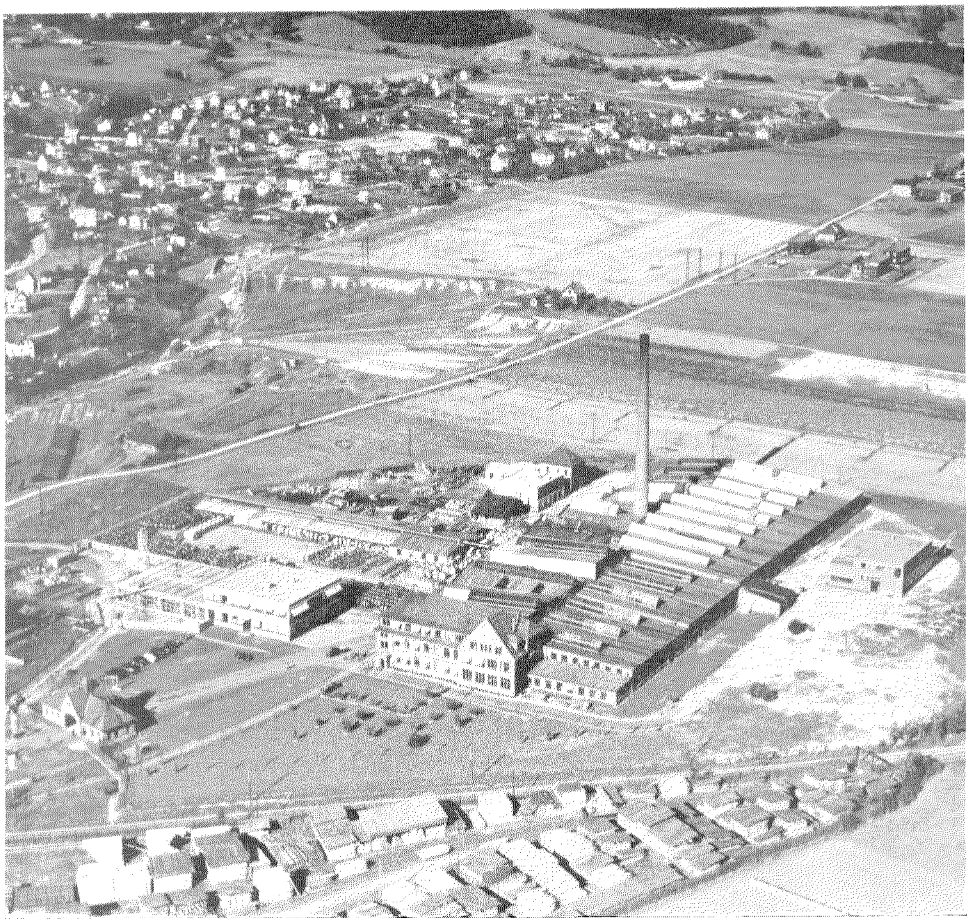

AIRPLANE VIEW OF THE MODERN PLANT OF STANDARD TELEFON-OG KABELFABRIK A/S, OSLO, NORWAY, FOR THE PRODUCTION OF BARE AND RUBBER INSULATED WIRE; TELEPHONE AND POWER CABLE; THE MANUFACTURE OF LOADING COILS; AND THE ASSEMBLY OF TELEPHONE APPARATUS AND EQUIPMENT. FLOOR SPACE OCCUPIED IS 150,000 SQUARE FEET AND THE SITE ON WHICH THE BUILDINGS ARE ERECTED CONTAINS 37 ACRES.

Electrical Communication in 1936

General Trend of Development

THE modern communication system is being formed increasingly by the progressive coordination of individual transmission paths of various types, capable of manual and more and more frequently of automatic selection and control. The means utilised for routing electric currents over such paths, together with adequate pick-up and reproduction facilities, provide the present day public with services which are continually improving in quality and expanding in variety: telephone, telegraph, facsimile, telephotography, teleprinter, etc.

In the switching field, the direction of development is in the provision of more complete automatic operation within areas of increasing size. The principal elements of such a problem are the long distance transmission of selective impulses, the control of the overall equivalent of the transmission path by means of the automatic insertion of repeaters with appropriate gains, and the recording of both the duration of the call and the tariff data involved. In certain cases alternate toll paths are automatically selected and the equivalent of manually prepared toll tickets containing all the pertinent information is printed automatically without the intervention of an operator.

These problems are solved principally by association of mechanical means with others adapted specifically to the transmission problem; the use of voice frequency currents for impulsing being predominant in the very long circuits, whilst for circuits of limited length lower frequencies are also used successfully. The problem of maintaining a given overall equivalent over complex circuits is one which may involve also the use of voice frequency signals destined to regulate the gain at given points.

The transmission paths themselves have been the object of a great deal of new thought during the last few years, due principally to the desire to obtain wider bands of communication. These wider bands may be made necessary by the increasing complexity of the characteristics of the signals to be transmitted or by efforts to obtain lower costs for individual narrow bandwidths separated from each other in the wide band system by means of appropriate sharp filters.

These wide-band transmission systems necessarily use higher frequencies and involve special types of conductors often of larger overall size than those previously used. On account of the higher attenuation resulting from the use of these higher frequencies, the development of stable amplifiers giving high gains over wide bands has taken a very important place in research activities. Outstanding amongst these is the use of reverse feed-back amplifiers and possibly, in the future, the application of secondary emission phenomena to amplification of weak currents.

Another phase of these new developments is the search for means of filtering a band of frequencies out of the wide band system, leaving a minimum of lost space between two adjacent channels. One of the most promising methods is the application of structures involving quartz crystal elements giving very sharp cut-off even at the highest frequencies, and this new technique is likely to be of basic importance in future multi-channel communication systems.

The wide-band systems of to-day may be found inadequate, in the future, for use in connection with more refined methods of television or for very large groups of telephone or facsimile channels, and it is natural to consider the possibilities of systems using ultra-high frequencies. In this case, one may conceive guides which may have physical transverse dimensions of the same order of magnitude as the wavelength of the currents to be transmitted. The effect of a tubular conductor or solid dielectric structure is then to canalise the wave in the interior of the cylinder: a technique intermediate between ultra-short wave radio systems, where the energy is directed through free space; and that of wire transmission, where the metallic conductor acts as the carrier for the currents transmitted.

To a certain extent developments in radio transmission are paralleling those in the wire communication field. Wide-band systems are being actively developed for television transmission, facsimile or multiplex telephony. They employ ultra-short waves as carriers and involve, in some cases, the use of radio repeaters. Development is also proceeding in the hyperfrequency range applied to direct transmission without guide.

Apart from these problems involving essentially the transmission of intelligence from one point to another, a new general line of development is opened by the increasing demand for positional knowledge of mobile systems in space.

In general the problem of communication from ships or aircraft to ground systems has been solved, but further research is necessary to provide means of obtaining readily exact knowledge of the position of a ship or airplane.

The problem includes the creation in space of characteristic zones which give the navigator the information required, either for travelling from one point to another, for landing without visibility, or for entering a harbour. Part of this technique involves ultra-short wave systems and recent automatic goniometric methods eliminating errors due to reflected waves or other causes.

Another problem, which is also part of the technique in process of development, is that of the transformation of visual phenomena into electric waves and back. The acoustical equivalent is already highly perfected, particularly with the introduction of binaural perspective and high fidelity systems; but the technique of transformation of visible pictures into electric waves is of a much more complex nature and is only in its infancy. Very remarkable progress has been made by means of scanning by an electron beam a suitable granular photoelectric surface, thus resolving the visible pictures into electric currents. The inverse phenomena have also been produced with success by means of appropriate cathode ray tubes. Future years, however, undoubtedly will see many new additions to this technique.

The future of wide-band systems using very high frequencies is consequently of outstanding importance. This line of development involves complex phenomena due partly to the higher frequencies involved and also to the necessity of measuring carefully quantities hitherto of secondary importance, such as the phase relationship of input and output currents in wide-band amplifiers for applying reverse feed-back, or the exact value of frequency and attenuation in a range for which measuring equipment so far has been very primitive. It would seem that much technical effort necessarily will be devoted to the elaboration of a measuring technique capable of coping with such new problems.

Progress in Communication Systems

Considerable activity has taken place in the extension and modernisation of European long distance systems, particularly in Great Britain.

During the year 85 new trunk cables to a total length of approximately 3,000 km., involving the construction of 1,600 km. of duct line, were provided in Great Britain. This represents an addition of approximately 600,000 km. of single wire to the British Post Office trunk system.

890 new inland trunk circuits, of over 40 km. in length, have been set up during the year. The longer routes show the larger increases, e.g., the number of trunks between London and Scotland has now reached 98, of which 55 have been provided since October, 1934. Between London and the West of England there are now 67 circuits, 55 of which have been provided since October, 1934. Nine additional Continental trunks, of which 5 are London-Paris circuits, have been brought into service during the year. Additional circuits were also provided for special occasions, the Olympic Games, Berlin, requiring 14 extra circuits, being an outstanding example.

Several important projects were completed and new construction started embodying the latest developments in the application of carrier telephony to underground cable systems. These included the complete laying of the London-Birmingham coaxial cable (290 km.)* designed for carrier telephony and television transmission, and the commencement of the extension of this cable to Manchester (210 km.). Included also is the Bristol-Plymouth non-loaded, multi-conductor, carrier cable* (involving two cables of 200 km. length) which has been completed together with the intermediate repeater and

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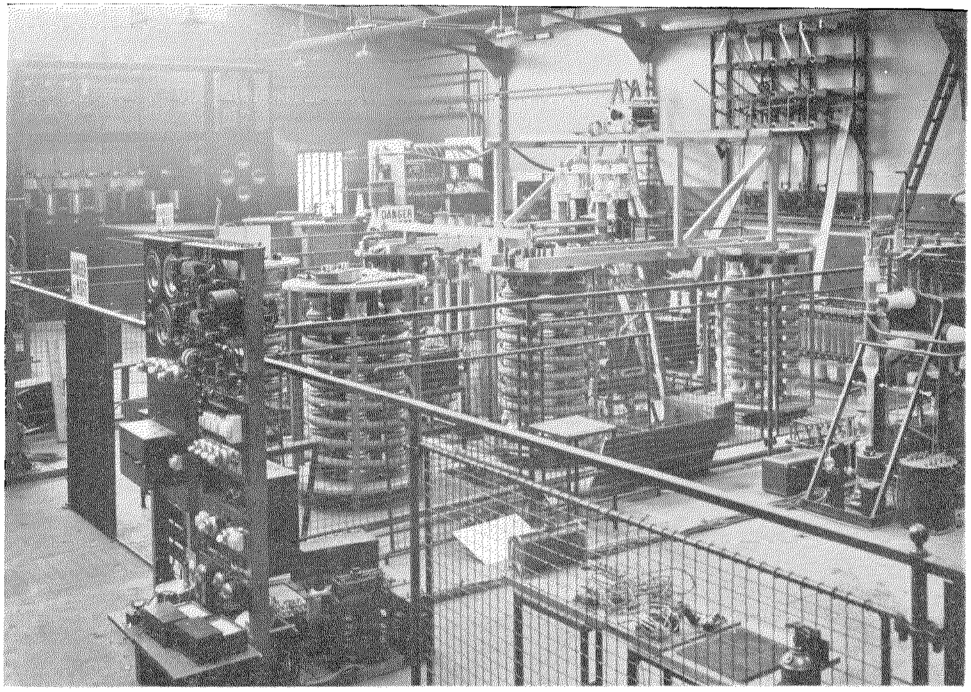
* Developed and installed by Standard Telephones and Cables Ltd., London.



Part of Vacuum Tube Testing Laboratory, Les Laboratoires Le Matériel Téléphonique.

terminal equipments on a 12-channel carrier per pair basis for a large proportion of the available cable circuits. The repeaters are spaced at distances of about 32 km. along the route and are designed on the negative feed-back principle. Several additional cable systems of the same general design are already planned for installation.

The Czechoslovakian system has progressed according to the plans laid down in 1935, 105 km. of modern cable having been completed during the year with a further 122 km. under construction.

The Danish long distance system has recently been considerably extended. In addition to the 73 km. of cable completed, a further 221 km. is now under construction with additional projects in view for 1937.

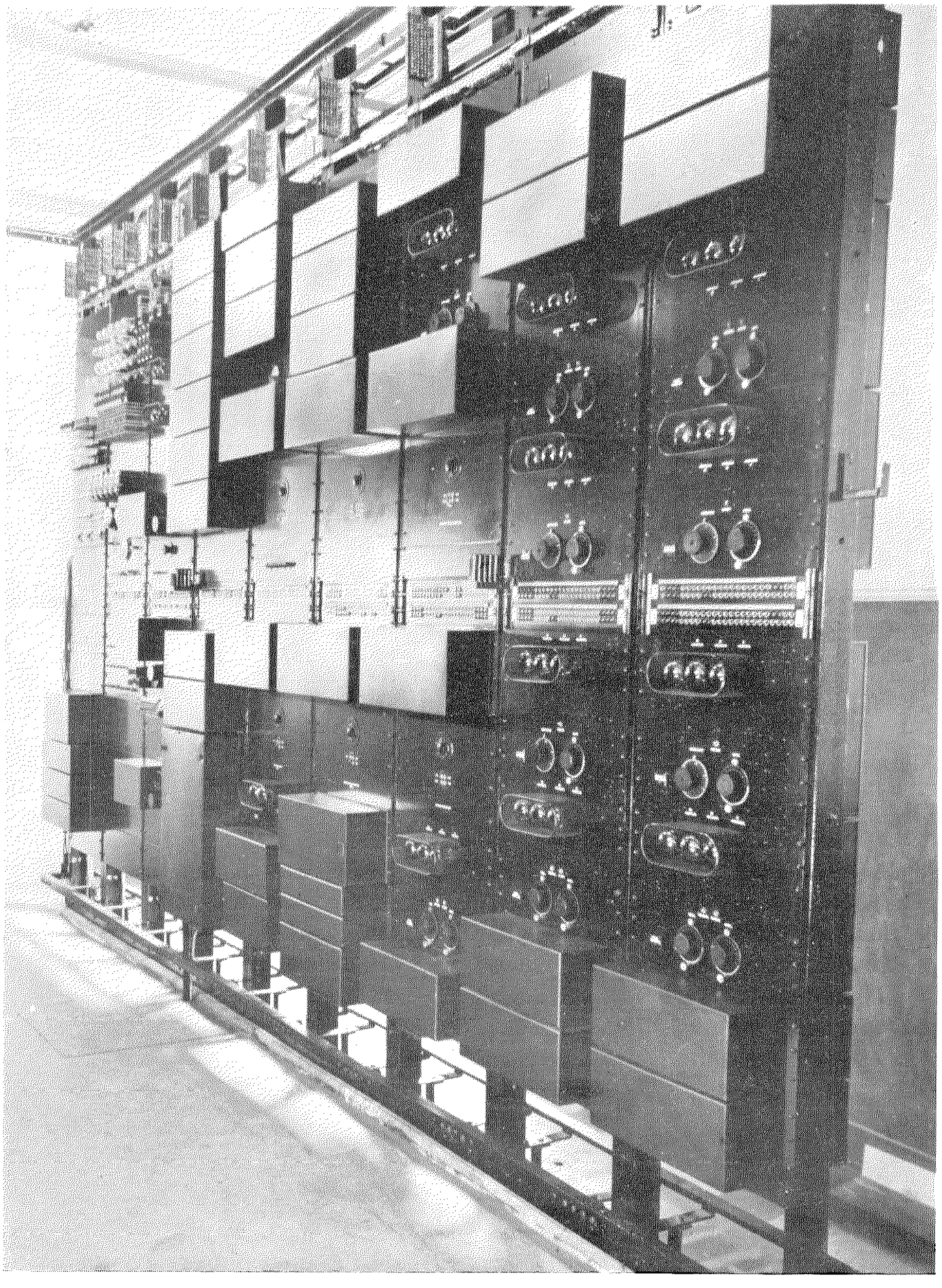
The Netherlands Administration completed and has under construction considerable extensions to their long distance system, including cables for carrier telephone operation. A cable network for telephone purposes, comprising 153 km., was completed for the Provinciale Noord-Brabantsche Electricitats Maatschappij (a power company in Holland).

In Italy, projects of the P. & T. Department are proceeding normally. An important telephone cable for the Salerno-Reggio Railway, comprising 425 km. of track route, was completed.

Norway has made considerable progress in its long distance system. 175 km. of cable were completed during the year with a further 114 km. under construction. Part of the supplementary repeater equipment involved was also completed and placed in service.

Sweden has continued its usual heavy programme of underground cable construction. During the year, 516 km. of cable were installed, together with new and extended associated repeater equipments.

The Swiss Administration has devoted considerable attention to the problem of subscriber-to-subscriber dialing, and a successful demonstration of an automatic, 50-cycle, toll dialing



Cable Terminal Equipment at Stanley, Tasmania: Australia–Tasmania Submarine Cable.

scheme was given during the year over a section of the Swiss underground network. Extensions to the network comprised 95 km. of cable completed with a further 68 km. under construction.

The Australia–Tasmania submarine cable was successfully completed and put into service early in the year. This 180 mile cable is, incidentally, one of the longest submarine telephone cables in existence, and was designed for five telephone and seven duplex telegraph circuits, as well as for a special channel for the transmission of radio broadcast programmes. In both Victoria and New South Wales, Australia, steps are being taken towards the installation of underground toll cable systems; also, in Australia and New Zealand, to extend the use of carrier systems.

Extensions to the South African telephone cable network have been completed and new systems are contemplated.

In Germany, considerable activity occurred in the application of carrier telephony and television to coaxial cables as well as in extensions to loaded cable systems employing single channel and 3-channel carrier systems.

In France, progress continues to be made in the extension of the long distance telephone system. Approximately 450 km. of cable were placed in service during the year with a further 800 km. under construction.

Construction of the non-loaded cable circuit between Tokyo and Mukden—over 2700 km.—is making definite strides through the collaboration of Teishinsho (Japanese Telephone and Telegraph Administration), Korean Communication Bureau, and the Manchukuo Telephone and Telegraph Company. The first section Antung–Mukden, and the second section Osaka–Nagoya, were open early in 1936. Cable installations over the Seoul–Heijo and Fusan–Fukuoka sections have already been completed and the terminal and repeater equipments will be installed by March, 1937. The whole route is scheduled to be completed early in 1938.

All the terminals and repeater equipments for this project are specified to be the Nippon Electric Company's standard 3-channel non-loaded cable carrier telephone and repeater system. This system, which is intended for use on multi-core non-loaded cable is the result of extensive research in Japan and embodies many important improvements.

In Japan other toll communication networks are also becoming substantially complete through the active installation of inexpensive multi-channel carrier telephone and telegraph systems.

At Singapore, a 65 km. underground cable telephone system is now under construction.

Progress has been made by the Chinese Telephone Administration in furthering its long distance communication project, involving communication by wire between important points in a number of provinces. The installation of toll switchboards and repeater station equipment for operation over the newly constructed open-wire toll network was commenced at the beginning of 1936 and the first portion is now completed. There are to date five such installations: Shanghai, Nanking, Yingkiahwei, Kiukiang and Hankow. Standard Telephones and Cables Limited, London, manufactured the toll boards, repeater equipment, and the cables for river crossings.

The cutting into service of these equipments permitted the inauguration of telephone communication over land lines between Shanghai and Hankow, a distance of approximately 650 miles.

Plans have been prepared and the equipment ordered for the extension of this toll network. During 1937, seven or eight new toll switchboards and repeater stations will be installed and placed in operation, thereby establishing long distance telephony on a large scale in China.

There are indications that traffic over certain of the circuits already provided will increase in the very near future to such an extent as to necessitate the provision of additional circuits. The use of carrier telephony to provide these circuits is under serious consideration.

The Argentine State Railway Administration Headquarters at Buenos Aires is now provided with telephone and telegraph communication with the State Railway lines in Northern Argentina over a 3-channel carrier telephone and telegraph installation linking its Buenos Aires offices with the important terminal and division offices at Santa Fé, Añatuya, Tucumán, and Cruz del Eje, a route distance of over 1600 km. Voice frequency carrier telegraph is superimposed on one of the telephone channels between Buenos Aires, Santa Fé, and Tucumán on which Creed printers are used for handling messages. The carrier equipment was manufactured by Standard Telephones and Cables Limited, London, and was installed by the Compañía Standard Electric Argentina and is one of the first installations of its kind in the world where 3-channel carrier telephony with superimposed voice frequency carrier telegraph has been applied to train despatching circuits.

Subscribers' Equipment

In the field of subscribers' sets, development is tending towards higher quality of transmitters and receivers as well as of the circuits themselves, with resulting elimination of noise, both extraneous and internal, in keeping with the efforts directed to removing noise from transmission systems and central office equipment.

The use of moulded local and common battery sets is being extended. Of particular interest is the advent of the convertible set introduced by the Bell Telephone Manufacturing Company, Antwerp. It offers the advantages of easy convertibility for use as a desk or wall set, as well as for local or common battery (either manual or automatic) working.

New and interesting developments in the P.A.B.X. field include an arrangement whereby two or three extension sets in multiple may call and intercommunicate with each other, ringing and talking current being supplied from the central office.

Further improvement has taken place in P.A.B.X. equipment with capacities ranging from 3 to 3,000 lines. New facilities and improved methods of operation have been embodied in attendants' sets and in the P.A.B.X's. themselves.

To enable a P.A.B.X. subscriber to rapidly obtain connections without the necessity of dialing, the Bell Telephone Manufacturing Company, Antwerp, has recently developed an "Executive Rapid Call Equipment." Essentially it consists of a telephone set with a key box at the subscriber's station together with an adaptor circuit at the P.A.B.X., calls being made to a limited number of subscribers on the same board by merely pressing the key designated for a particular subscriber.

An interesting new development of Standard Electric, Budapest, is the so-called Home Coin Collector Box. It is attached to the subset and serves the purpose of preventing summer guests, boarders, or visitors from using the telephone without payment.

Subscriber Set Equipped with Budapest Home Coin Collector.

Remote Control and Signaling Systems

The application of remote control and indicating systems is being extended rapidly. Power Supply Authorities for large areas, either sparsely or densely populated, are finding it necessary to create within their own areas a central control point for control and remote indication of the major substations and the smaller lower voltage satellite substations. Owing to the large number of such stations, any remote control and indicating system to be attractive, must be relatively inexpensive and must occupy minimum space in the control room. A "Line Finder" system, meeting these requirements, has been developed. It provides the greatest possible flexibility for extensions.

Advances in railway signaling systems have continued, a notable instance in this connection being the Dial Train Control System which has been standardised by the L. & N. E. Railway of England. Systems have also been developed providing a method of indicating at some central point the position of a large number of track circuits (whether occupied or clear) over one common line channel.

It is apparent that the technique of railway signaling is undergoing a change, the most obvious result of which will be the gradual elimination of lever control of signal frames and the introduction of a system whereby the operation of the various points and signals is controlled from a desk provided with a track diagram.

A similar technique is also being employed in the remote control of street lighting, remote indication of fuse ruptures, etc., etc.

Telegraph and Teleprinter Systems

Growth in telegraph traffic in Great Britain has been met by expansion of the 18-channel voice frequency system. The 4-channel system which was introduced in 1935 between London and Oxford has proved satisfactory and has been applied to other suitable routes.

An experimental 12-channel system was opened in January, 1936, between London and Paris and has been operated with success.

For use on V.F. systems generally, a static transmitting unit consisting essentially of a high grade transformer and a number of dry rectifiers in bridge formation has been introduced and will eventually be fitted on all "Standard" systems, thereby giving greater stability and economy in maintenance by eliminating the moving contact of the transmitting telegraph relay.

The use of teleprinters for handling telegraph traffic has now been generally adopted by Telegraph Administrations, and the C.C.I.T. has fixed the code and standards of performance required for machines used on International communication channels. Development work in 1936, therefore, was largely directed towards perfecting the design and manufacture of teleprinter systems in order to improve their performance and reduce maintenance costs.

A combined keyboard perforator and automatic tape transmitter* to provide Telex subscribers with a most efficient means of transmission in a convenient and compact form has been developed. The apparatus enables messages to be prepared in the form of a perforated paper tape before the initiation of a call. Keyboard operator delays are thus eliminated from the actual line transmission time, the messages being transmitted automatically at the maximum speed of the apparatus.

Teleprinter exchange subscribers in Great Britain have increased. Following the recent introduction of International Telex services, future growth is likely to be rapid.

A commercial Telex service was opened between Great Britain and Holland in May, 1936, and a successful service was also maintained between Great Britain and the Olympic Stadium in Berlin during the 1936 Olympiad.

The C.C.I.T. and C.C.I.F. having adopted 1,500 p:s as the standard frequency for International Telex operation (on a single channel carrier basis), it was decided to convert the Inland Telex system in Great Britain from the frequency of 300 p:s previously used to 1,500 p:s.

The introduction of ancillary working in the British Inland Telegraph Service to cope more efficiently with the increase in traffic following the reduction of telegraph rates in 1935, has necessitated the provision in 1936 of a further 500 Creed teleprinters. These machines are fitted with answer-back units, especially developed for use in conjunction with the switching equipment, in order to dispense with the need for acknowledging telegrams as received.

Administrations in Europe and elsewhere are extending the use of teleprinters. In France, an additional 100 Creed teleprinters have been supplied for the National Telegraph Service. The Swedish National Telegraph News Services will increase their facilities by the addition of a total of 50 teleprinters.

Following the introduction in 1935 of the Johannesburg stock exchange service, which employs Creed teleprinters, a similar service was inaugurated in Sydney, Australia, in March, 1936, and similar services will be opened soon in Melbourne and Adelaide.

A teleprinter broadcast system has been developed for use in Great Britain to diffuse information on a full or partial broadcast basis; also a system for use in conjunction with standard P.B.X's. and apparatus on the ordinary telephone extension. In the latter case, when the lines are not required for broadcasting, the normal telephone and Telex facilities are available but, on operating the broadcast keys, the lines are transferred from the P.B.X. to the broadcasting equipment.

Radio Broadcasting

Attention continues to be focussed on improving the power efficiency of broadcasting transmitters. The use of high power modulation has been still further developed and it is now possible to obtain high efficiency, high fidelity, class "B" push-pull modulators incorporating

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* Developed by Creed & Co.

"Black" feedback for carrier powers up to 100 kW. Another method of attacking the problem, put forward by the Bell Telephone Laboratories, is applicable to low power modulation systems and involves a power amplifier stage of two valves, one valve being connected directly to the output circuit and one through an impedance inverting network and operative only on the peaks of modulation. In a third line of development, all valves are driven at constant amplitude and high efficiency, the modulation being effected by combining the output of two amplifier systems with phase-modulated drives.

European broadcasting has exhibited a continuation of the tendency to operate all stations at high power, particularly in those cases where the station has sole use of a wavelength. An aerial power of 100 kW. is now common.

In Czechoslovakia, arrangements are being made for the installation of a new 100-kW. station and the replacement of a low power by a 100-kW. station which can be extended to 200 kW. Another 100-kW. station is contemplated.

Sweden is installing a new 100-kW. station and is contemplating further stations of similar size. In addition the network of low power relay stations in that country and in Norway is being extended to take care of the peculiar geographic problems encountered.

The advantages of the high mast radiator are being increasingly recognised and practically all new high power stations in Europe will be equipped with some radiator of this type.

A 910-foot Blaw-Knox radiator is being installed at Liblice, Czechoslovakia. It will be the second tallest mast in the world, the tallest being at Budapest. The new 100-kW. Czechoslovakian station will also have a vertical radiator of this type. The British Broadcasting Corporation now has two examples of such radiators, one in Northern Ireland and one at the new Scottish station at Burghead.

In connection with these mast radiators, the "shunt excitation" system introduced by the Bell Telephone Laboratories is of special interest. While it has hitherto been considered necessary to insulate mast aerials so as to apply the excitation in series with the mast, under this new scheme the mast is connected to ground and the power is applied through a short single wire transmission line to a point on the mast at some height above ground of the order of one-tenth wavelength. This system considerably simplifies the provision of aircraft warning lights, now generally required on all high structures. Obviously, it may have appreciable economic reactions on the mechanical design and cost of the structure for a given height.

The British Broadcasting Corporation has continued the development of its scheme of distribution, and during the past year has put into service a number of high power stations to replace earlier and low powered stations. In addition to these developments in the B.B.C. "Home" service, a rapid expansion of the Empire service is taking place with the object of improving the strength and reliability of receptions from Daventry.

A new transmitter building has been erected at Daventry to house four high power short wave transmitters. Eight additional masts are being erected to support new aerial arrays, which have been designed as an outcome of experiments carried out since the Empire station at Daventry was placed in service in 1932.

Common wavelength frequency control equipment is being introduced on eight of the B.B.C. transmitters, and other European countries are studying this system as a means of solving the problem of wavelength congestion.

In Australia, the regional transmitters, installed by Standard Telephones and Cables Ltd. in the past year, are now coming into use and it is anticipated that further expansion of the service will be made to meet the public demand.

New Zealand is also increasing the power of its stations.

The Government of India have indicated their intention of proceeding with an extensive network of broadcasting stations, both medium and short wave.

It is understood that the two 150-kW. broadcasters for Tokyo station JOAK, the manufacture of which is reported to be almost complete, will be placed in operation in the Spring of 1937.

In connection with the regular international broadcasts by the Japan Broadcasting Association, the Japanese International Telephone Company ordered a new high power short wave transmitter and speech input equipment. The 50-kW. transmitter utilises low power modulation and is under test in the Nippon Electric Company's factory. It will shortly be installed in the Nazaki Station of the Japanese International Telephone Company.

The installation at Canton, southern China, of a 50-kW. broadcast station to replace the existing 1-kW. station is proceeding. It is anticipated that the new equipment will be ready for cutting into service early in 1937.

It is of interest to note that increasing use is being made of extremely short wave links for communication between broadcast networks and outside broadcast points which cannot normally be connected by wire.

Commercial Radio

Outstanding international radio telephone services inaugurated in 1936 include: Paris–New York; Tokyo–Shanghai; Tokyo–Cape Town (via London); and Tokyo–Rio de Janeiro (via Berlin). A similar service between Japan and French Indo-China also was started and negotiations are in process for a link between Tokyo and Bangkok.

Chinese authorities have been carrying out tests with England and America for the purpose of establishing radio telephone communication in the near future.

During 1936 short wave radio telephone links were established between Shanghai and Hankow, and between Shanghai and Canton. Facilities are provided for connecting the equipment at the terminals to the local telephone systems.

In the delta of the southern rivers in Kwangtung Province, China, a number of ultra-short wave equipments are being provided for telephone communication between various cities. The circuits radiate from Canton. Western Electric equipment is employed.

A radio telephone service between Great Britain and Kenya, East Africa, was inaugurated in March. Through submarine telephone cables Ceylon and Tasmania have been included in the international radio telephone network via India and Australia, respectively.

C. Lorenz-A.G., Berlin, provided an installation of four short wave transmitters for the Olympic Games in Berlin. These transmitters were the results of extensive development work and had to meet the following requirements: 40 kW. output in telephony; highest stability of frequency; percentage modulation 80%; and quick changeability of wavelength. These transmitters form the focal point of the directional antenna system which directs programmes towards North, Central, and South America, Africa, and South and East Asia.

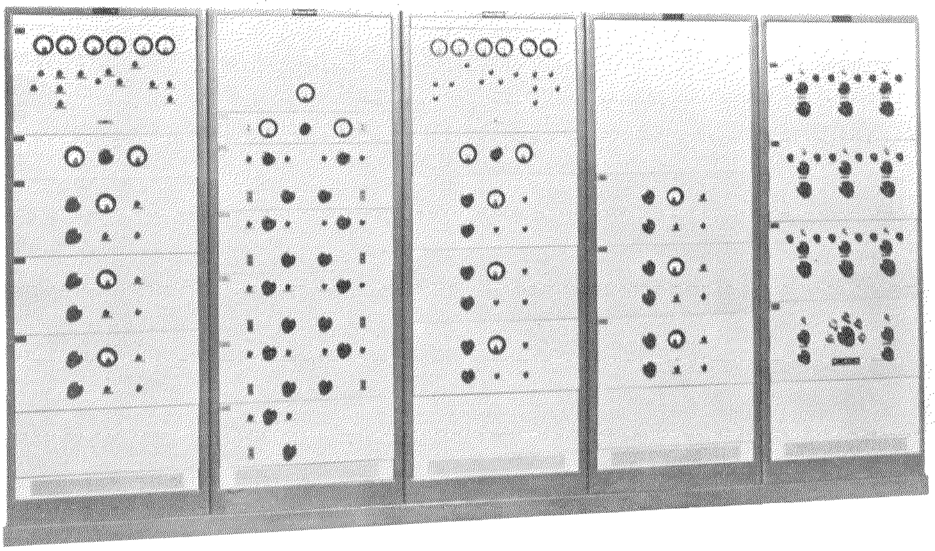
A considerable amount of experimental work on ultra-short waves continues to be carried out in all parts of the world. Evidence has been brought forward to show that on wavelengths below 250 cm. variations in atmospheric refraction or reflection (or both) from temperature inversion layers in the lower atmosphere may be definite factors in producing fading. Contrary to expectation, there also are indications that wavelengths between 5 and 10 metres may have a range of several thousand miles. In any case, equipments working in this band cannot always be considered as providing only a local field and the question of interference with remote stations may require attention.

Beginning with the latter half of the year, a 9-channel ultra-short wave link between Stranraer (Scotland) and Portpatrick (Ireland) has been operating on an experimental basis and is expected to be cut into regular service early in 1937. This link, which was ordered by the British Post Office to form part of its regular telephone network, will be the first single carrier, multi-channel radio link to be placed in commercial service.

An interesting radio telephone link is that to the island of Guernsey. This link employs 250-watt transmitters each handling two channels. The distance covered is 85 miles, approximately 1.7 times the optical range. Wavelengths of 5, 5½, 8, and 8½ metres are used.

Since the end of 1935, Teishinsho has been experimenting on the trial ultra-short wave telephone circuit over Tsugaru Strait (Aomori–Hakodate, 100 km.) with satisfactory results, using trial equipments. Recently an order has been issued for two transmitters with an output of about 50 watts and two receivers designed to provide six channels on one carrier utilising alternative wavelengths of 4 and 6 metres. The equipment is now under construction by the Nippon Electric Company.

A further application of ultra-short wave working is found in the Radio Corporation of America's experimental link set up between New York and Philadelphia. This link is intended to carry



Stranraer (Scotland) and Portpatrick (Ireland) 9-Channel Ultra-Short Wave Radio Telephone Link—Transmitters and Channel Modulators.

facsimile channels and uses 75-watt transmitters. The distance between the terminals of 91 miles is covered not in one step but with the introduction of two relay stations. The system operates on wavelengths of about 3 metres.

During 1936 an ultra-high frequency radio system was developed, installed, and placed in successful operation by the Mackay Radio and Telegraph Company between its New York central operating department and its main radio telegraph transmitting station at Brentwood, Long Island, for the remote control of radio transmitters by the central operating department, involving the use of a carrier frequency of about $3\frac{1}{2}$ metres and power of 80 watts, carrying six tone channels which it is intended to increase to eight in the future. Transmitters and receivers with semi-automatic switching facilities are installed in duplicate to ensure continuity of service. The distance from transmitter to receiver is 41 miles.

A number of new inventions and developments were made during the year on high frequency antenna systems, resulting in new types of radiation arrangements and tending towards greater efficiency with lower capital costs. The resulting improvements were incorporated in the new antenna structures recently built by Mackay Radio.

Increasing interest is being shown in the use of ultra-short wave radio equipment for police use. The United Telephone and Telegraph Works, Ltd., Vienna, in conjunction with the Austrian police authorities successfully demonstrated such a system to representatives of many European police organisations.

Patent Suit

On October 14, 1936 the United States District Court, Eastern District of New York, handed down an opinion in a suit brought against the Mackay Radio and Telegraph Company for alleged infringement of five patents relating to directive antennas. The Court held that the antenna structures erected by Mackay Radio did not infringe any of the claims of the patents and that, furthermore, the antennas used by Mackay Radio were actually more efficient than could be constructed under the patents in the suit.

Television

The British Broadcasting Corporation are conducting commercial television transmissions on two systems: the E.M.I. (Marconi-H.M.V. group), and the Baird. Both these systems are installed at the B.B.C. television studios in Alexandra Palace and are employed alternately. The subjects televised include open-air shots, studio programmes, and films.

Some six of the larger British manufacturers are offering television receivers which range in price from about £85 to £120 and function on either of the two transmission systems employed by the B.B.C.

The French P.T.T. are transmitting one hour per day on an experimental basis. Direct pick-up transmissions are made from a studio at Rue de Grenelle. In the recent Paris Exhibition five television transmitters were shown in operation together with a large number of receivers.

French experimental telecinema emissions, using the same transmitter, will start early in 1937.

Les Laboratoires L.M.T. completed their second television system (the first was shown September, 1935). In cooperation with Le Matériel Téléphonique, this system was demonstrated at the Radio Exhibition. Motion picture films only were employed as programme sources.

The most recent demonstration of television in Italy was at Milan in April, 1936. The equipment employed electronic scanning for transmission and cathode ray tubes for reception. Research in Italy is being carried on in all details of transmission and reception, including the development of a suitable television transmitter to cover a service radius of 30 km. on a wavelength between 5 and 7 metres. For cine-films, 240 lines, 25 images per second were used. For daylight pick-up, 120 lines were employed. The receiver for combined vision and sound reproduction employed 13 valves.

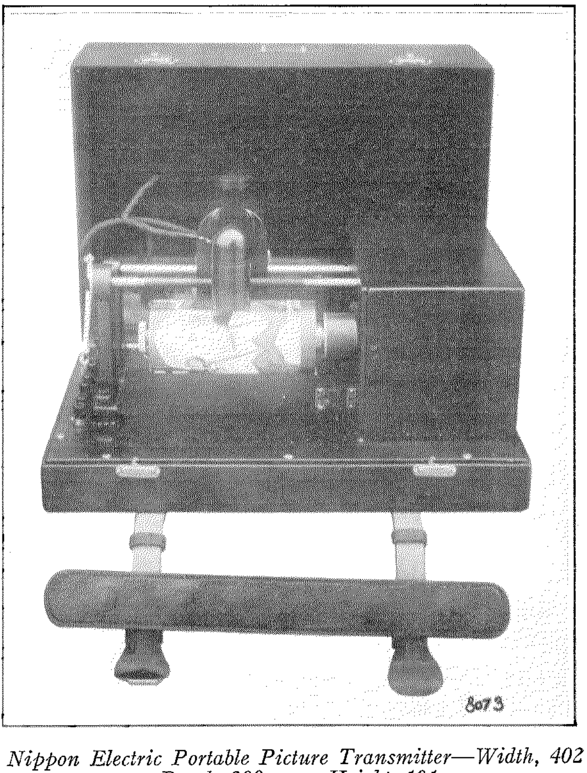
The number of exhibits at the Berlin Radio Exhibition in 1936 indicated that development work on television is very active in Germany. The television transmitter at Witzleben, which is transmitting programmes two hours daily, is connected by means of coaxial cables to the Berlin television studios, to the site of the Olympic Games, and also to Nurnberg and Leipzig.

In the United States of America, the Radio Corporation of America have installed a television transmitter in the Empire State Building in New York City, connected by coaxial cable to the National Broadcasting Company's studios in the R.C.A. Building about a mile away. Experimental programmes are being broadcast from these studios.

Other American companies also are active in the field of television. The Bell System has installed an experimental coaxial cable system between New York and Philadelphia which will be available for television experiments.

Picture Transmission

Teishinsho, since 1935, had been experimenting with picture transmission over the 2,300 km. radio link between Tokyo and Taihoku, Formosa, employing Nippon Electric equipment. Encouraged by the results of the above transmission, Teishinsho, the Allied News, and Nippon Electric jointly undertook the first Europe–Asia radio picture transmission, taking the opportunity of the Eleventh Olympic Games held in Berlin in August. By arrangement with the



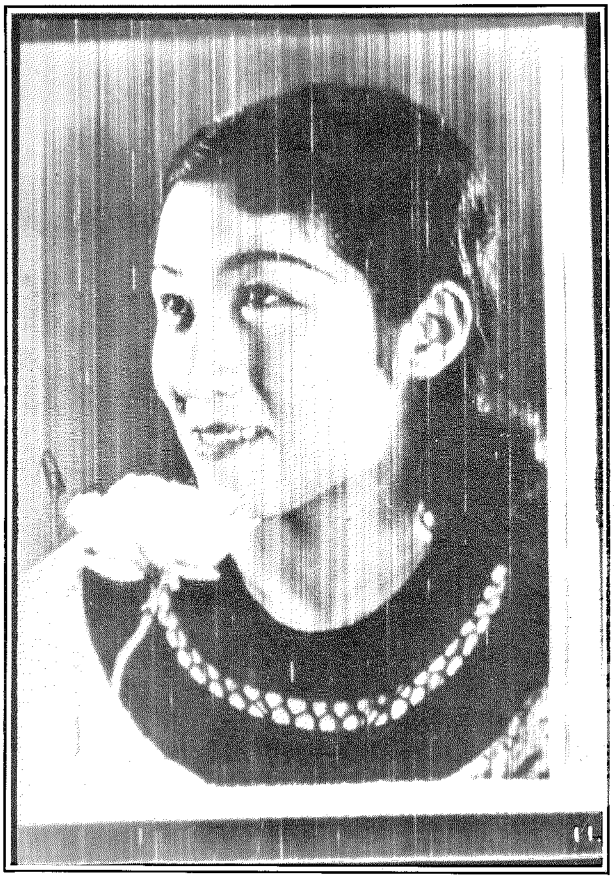
Nippon Electric Portable Picture Transmitter—Width, 402 mm.; Depth, 280 mm.; Height, 191 mm.

German Reichspost, Nippon Electric sent Japanese engineers and a complete set of No. 19–B radio picture transmission equipment to Berlin. This equipment is the newest model in which switching-over between time modulation and amplitude modulation can easily be performed as desired according to the conditions of the radio circuit.

The first part of the experiments was conducted with Nippon Electric's receiver in Tokyo and Siemens and Halske's transmitter in Berlin over the period from July 1st to August 17th. Time modulation system with a dot frequency of 170 cycles was employed for this experiment, and picture transmission was performed over a carrier circuit of 14,665 kc. between Nauen DFD Transmitting Station and Komuro Receiving Station, Japanese International Telephone Company, where two beam antennas for space diversity reception were used. Slight changes in the scanning density and speed of rotation were made in Tokyo in order that interworking between the Siemens and Nippon systems might be satisfactorily accomplished. The control operation from Tokyo was performed over a 15,750 kc. circuit. Pictures of the Olympic Games were printed in the Tokyo morning papers of the next day.

In the second part of the experiments, made during the three weeks that followed the Olympic Games, Nippon Electric equipments were used in Berlin and Tokyo and transmission was conducted in both directions. In this case both time modulation and amplitude modulation systems were employed with success. For the former system, an optical time modulation set employing a photo-cell was provided in the transmitter, and a special neon tube limiter was used for reception, while in the amplitude modulation the picture transmitter was coupled directly with the radio transmitter and a special device was fitted on the receiving side in order to minimise fading. High hopes are now entertained of the future of commercial picture transmission over radio links between Japan and Germany.

The transmitter was then moved to London, and the London–Tokyo trial transmission was started on November 17th with the collaboration of the British Post Office.



Picture Transmitted September 12, 1936, by Nippon Electric System from Berlin–Nauen DFD to Komuro–Tokyo. Received with Audio Automatic Volume Control using 2-Beam Antennas for Space Diversity Reception (Amplitude Modulation).

Marine and Aviation Radio

Marine. The unqualified success of the radio equipment* on the R.M.S. Queen Mary has been an outstanding event of 1936. It was only fitting that such a ship should be provided with an installation capable of meeting the demands of what promised to be a very remarkable maiden voyage. This promise was more than fulfilled; on this single voyage a radio telegraph traffic of over 275,000 paid words, 291 radio telephone calls to all parts of the world, and 40 separate broadcast programmes, made a record highly gratifying both to the equipment designers, the operating staff, and the Cunard White Star Line.

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* "The Radio Installation on the Cunard White Star, R.M.S. Queen Mary," by H. Thorpe-Woods, H. H. Buttner, and E. N. Wendell, *Electrical Communication,* July, 1936.

This equipment includes a 3-kW. medium wave and a 3-kW. long wave transmitter together with two 400-watt short wave transmitters, all remotely controlled from the receiving room with respect to power, keying, and selection of spot wavelengths. The receiving room includes facilities for reception on 8 different channels simultaneously.

A new system of duplex transmission, which enables two messages to be sent simultaneously from one radio transmitter, has been tested from the Portishead Radio Station. The messages are transmitted on two neighbouring frequencies, separated by approximately 10 kc, by the use of a high speed thermionic switching device. The tests show that the system is workable and that satisfactory reception of either of the two messages is possible by the usual type of ship's receiver.

In April, 1936 Teishinsho installed a Nippon Electric short wave radio telephone equipment on the N.Y.K. liner S. S. Chichibu-Maru, and the first ship-to-shore service on the Pacific was opened to the public on August 8th with very satisfactory results. The equipment comprises a 2-kW short wave, crystal controlled transmitter, a 19-valve superheterodyne receiver (both operating on the frequency range of 4–20 megacycles) and a special 4-wire system telephone repeater which is provided with a CODAN apparatus. Beginning in November, the service was extended to include Canada, the United States, Cuba, and Mexico.

Teishinsho are now considering equipments for the S. S. Yasukuni-Maru, a more up-to-date N.Y.K. European service vessel, and the S. S. Asahi-Maru, a Tokyo–Formosan liner. The former vessel is tentatively scheduled to take the Imperial Party to England for the Coronation Ceremonies.

The Mackay Radio and Telegraph Company, in the field of ship equipment through the Laboratories of Federal Telegraph Company, has developed an automatic alarm receiver, also improved and simplified ship transmitters of low power primarily for emergency and life boat use, to meet the requirements of the Safety of Life at Sea Convention recently ratified by the United States Government.

Aviation. During recent years the increase in aircraft traffic has necessitated the use of more wavelengths and as many as six are employed for general aircraft navigation in Europe. The use of these six wavelengths has naturally complicated the radio equipment. In addition short waves are employed for long distance routes, particularly in the tropics for communication with ground stations and between planes.

This increase of traffic has also necessitated the use of more than one airport at important terminals. At London, for instance, traffic is now brought in by the Croydon radio control to the Croydon controlled zone, and then handed over by radio to the Croydon, Heston, and Gatwick controlled zones for landing. Besides the instantaneous wavechange facilities for transmitters and receivers, this system has also necessitated the fitting of each of these airports with Lorenz blind approach equipment and the equipping of aircraft approaching Croydon with three-wavelength ultra-short wave receivers.

In order that navigators may be able to find their positions immediately most Aviation Operating Companies are now fitting direction finding apparatus on the aircraft, thus making direction finding work independent of the airports and enabling the latter to deal with more traffic.

Since the introduction of direction finding apparatus on aircraft, and the allocation of yet another wavelength for broadcasting weather reports, there is a tendency to use more than one receiver. The pilot thus may receive weather reports independently of the normal communication channel. Each of these receivers, if necessary, acts as a spare for the other in case of emergency.

The extension of the Imperial Airways services through the British Empire has involved the provision of many new ground stations for direction finding and for communication purposes along the various routes. Particular attention must be paid to the importance of radio on the Pan-American Airways' transpacific route, which involves "hops" of between 1,200 miles and 2,400 miles. On this route the position of the machine is determined every half hour by means of ground direction finding stations operating on the Adcock basis. Owing to the length of the "hops," it has been necessary habitually to take bearings at distances far beyond those hitherto considered reasonable.

The success of the Lorenz blind approach system is demonstrated by the fact that equipments have been, or are being, installed in a number of important airports throughout the world.

An extensive ground station network involving

STANDARD RADIO STAND—PARIS EXHIBITION

Norway, Sweden, and Finland is in course of installation. In addition to normal communication facilities, Adcock direction finding and blind approach systems will be included. In South Africa a network of ground stations, including Adcock direction finders, has been completed.

The Air France route to South America is now being completely equipped with Adcock direction finding stations.

At the International Aviation Show held in Paris in November, the French Air Ministry exhibit gave prominence to the R.C. 5 Radio Compass,* a model of which was displayed. In addition a small scale model showing the installation of an R.C. 6 Ground Direction Finder was on view. The fighter aircraft set of Standard Telephones and Cables Ltd., London, also attracted a good deal of interest since it was the only electrically remote-controlled set exhibited.

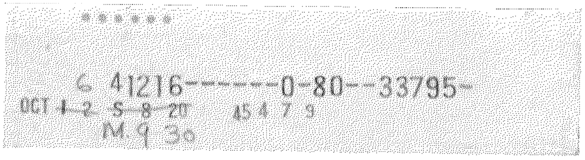
Rotary and Automatic Ticketing

The conversion of the Paris telephone network from manual to automatic, started in 1928, is now virtually complete, the whole of the Paris city area being on a full automatic basis with the exception of one office (8,000 lines to be cut over in 1937). There are 37 offices equipped for 330,000 lines.

The Paris suburban area comprises seventeen offices (equipped for 63,900 lines) either in service, under construction, or in process of installation. In the city area 25 offices (214,000 lines) and in the suburban area 10 offices (39,600 lines) were supplied by Le Matériel Téléphonique.

The Paris automatic telephone network will be extended to include the Paris regional area, designated "Zone No. 1," which takes in all places situated within a radius of 25–30 km. from Paris.

History was made on December 7, 1936 when the first installation for the automatic ticketing of toll calls was put into commercial operation by the Belgian Government. As its name implies, the system produces automatically a ticket on which is recorded the number of the calling party, the number of the called party, together with the town prefix, the rate, the duration of the conversation in minutes, the time, and the date.



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First Ticket Charged by the Belgian Administration with the Aid of the New Automatic Toll Printing Register. The Corrections are Due to the Fact that the Ticket was Printed while the Equipment was still under Test and the Machines were not all set to the Correct Date and Hour.

The system has been designed as an integral part of the rotary automatic system and may be easily applied to existing rotary type exchanges which were installed long before automatic ticketing was thought to be commercially practicable. In fact, this first installation was added to the Rotary 7–D Exchange in Bruges and to similar exchanges along the Belgian coast where a multitude of visitors from all over Europe congregate during the summer season. Because of this great influx of visitors, the seasonal variation in traffic is very great. With automatic toll ticketing, variations in regional traffic make little difference since there is no manual operating force to adjust to meet the changing traffic conditions. The success of this first installation resulted in the Belgian Administration placing orders for the extension of the system in the Bruges area.

Automatic toll ticketing may be applied to various purposes and in whole or in part. For example, it may be used generally in connection with suburban services to avoid the making out of a multitude of tickets for low-priced calls. On the other hand, it may be applied to a limited extent in connection with international or long distance calls, in which event it is not necessary to utilise identification equipment or make the recording equipment available to more than a few groups of important subscribers desiring international or long haul toll service on a full automatic basis. Examples of such subscribers are banks, exchanges, and important commercial houses having frequent occasion to telephone, say, from Brussels to Paris.

The development of automatic ticketing is the joint effort of the laboratories of the Bell Telephone Manufacturing Company, Antwerp, and Les Laboratoires L.M.T., Paris.

The rotary automatic system is now installed in 815 exchanges in 39 countries and the total lines installed or on order at the end of 1936 exceeded 1,960,000.

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* "The Automatic Radio Compass and Its Applications to Aerial Navigation," by H. Busignies, *Electrical Communication*, October, 1936.

During 1936 six digit dialing was introduced in the Budapest automatic telephone area.

National Dialing

A field trial of the rotary automatic toll system was carried out in Switzerland between the towns of Faido and Zurich. The cable circuit was built up by loops to total approximately 800 km., and equipment was put into service to represent an originating and terminating toll exchange with two intermediate tandem exchanges. Included were six standard two-wire repeaters with two of these repeaters connected automatically at the tandem points. For dialing, the new low voltage 50-cycle signaling system was used.*

The field trial was in every way satisfactory and equipment for a new full automatic toll exchange in Zurich was ordered by the Administration. Expressed in number of toll lines, switching and signaling equipment is foreseen for a total of 880 toll lines with the possibility of growing to three times this number.

The rotary automatic toll system was also demonstrated in Haarlem, Holland, in which country national dialing is also moving ahead.

Step-By-Step

The increase in the number of new subscribers of the British Post Office in 1936 was 416,000 as compared with 350,000 in 1935; the net increase was 230,000 in 1936 as compared with 180,000 in 1935.

The automatisation of exchange plant in Great Britain has been greatly accelerated. The number of automatic exchanges opened during the twelve months ending September, 1935, totaled 258, including 51 major exchanges. This figure is exactly twice that for the previous twelve months. For rural areas three sizes of unit automatic exchanges have been standardised, namely, 100-, 200-, and 800-line exchange types. All these types incorporate the new Post Office relay, and the two larger sizes also include the new Post Office standard 2-motion selector.

To improve the quality of the various tone signals in automatic exchanges and to obtain a greater measure of uniformity in these tones, an inductor tone machine has been developed to replace the tone drums hitherto used.

Equipment installed experimentally in the Folkestone automatic area to replace the "number engaged" tone by an aural announcement of the word "engaged" has had the effect of reducing from 11 seconds to 6.5 seconds the period the switches are held by the subscriber after the application of the engaged signal. The extension of this facility to trunk and toll calls is now under consideration.

Automatic traffic recorders, which record automatically the amount of traffic handled by a group of automatic switches, have been developed, and are now being installed at all except the smallest type of automatic exchange. This will enable a closer watch to be kept on the growth of traffic, and thus ensure adequate provision of switching plant at all times.

A speaking clock was made available to London subscribers in July, 1936. Subscribers on manual exchanges by asking the operator for "time" and subscribers on automatic exchanges by dialing "TIM," are connected to the clock and hear the time announced accurately to within 1/10th second. Calls are now ten times the number made previously, and in view of the evident utility of the service its extension to other areas is under consideration.

Installation of automatic telephone exchanges in Japan is making continuous progress. During the year fourteen step-by-step exchanges, with a total capacity of 53,200 lines, were opened by Teishinsho.

Increase in private branch exchange installations in Japan during 1936 is estimated to be at least 30,000 lines.

An important addition has been made to the Buenos Aires terminal communication network of the Buenos Aires Great Southern and Buenos Aires Western Railways, now working under joint management. This addition consists of three exchanges of 250, 150, and 80 lines, respectively, which interwork with the existing 300-line 7–B Rotary automatic exchange at the Plaza Constitucion office. The entire network of 780 lines is one of the largest privately owned automatic P.B.X. systems in South America.

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* "A Field Trial of 50 Cycle Signaling on Toll Lines," by W. Hatton, *Electrical Communication*, October, 1936.

International Telephone and Telegraph Corporation Operating Companies

Based on preliminary results for the year 1936, eight of the subsidiary Operating Companies of the I. T. & T. show station gain greater than in the corresponding period of 1935. The 1935 station gain figures, incidentally, were exceeded only by those of 1929 and 1930. In 1935 the gain was 58,000 telephones, while in 1936 it was slightly over 72,000 telephones. (The 1936 gain includes only the first six months' results of the Spanish Telephone Company, as they are the latest data available.) Every major company showed a substantial gain for the year, with the companies in Argentine, Rumania, Chile, Shanghai, Cuba, Mexico, Porto Rico, and Peru contributing most heavily. The toll traffic handled by these companies was the best in their history and estimates are that (exclusive of the Spanish Telephone Company) the results for 1936 will surpass those for 1935 by 12.3%.

In all these companies, plant extensions were carried out during 1936 to meet the increased demand for service. Important new toll lines were constructed and the capacity of existing lines in several territories was increased by the application of carrier systems.

A line constructed from Antofagasta, Chile, to Iquique connected the telephone system of the latter for the first time to the national Chilean network, and thus to the international network.

In September, 1936 the City of Lima, Peru, joined the ranks of cities which have an entirely automatic telephone system. As a result of further additions to automatic equipment during the year, every provincial capital city of Cuba is now on a full automatic basis. Four new dial central offices were added to the United River Plate system in Argentina and various magneto offices in the outlying sections of the country were converted to common battery working. An important dial installation took place in Porto Alegre, southern Brazil, and further progress was made with the automatic programme in Chile and Rumania.

Three important radio telephone extensions during 1936 involved these International subsidiary companies. The inauguration of service between the United States and Porto Rico in February, 1936, is of special interest because of the large trade with Porto Rico and the rapidly growing tourist interest in this Island. Radio service also was opened between Porto Rico and Santo Domingo; also between Lima, Peru and Antofagasta, Chile.

Power Line Carrier

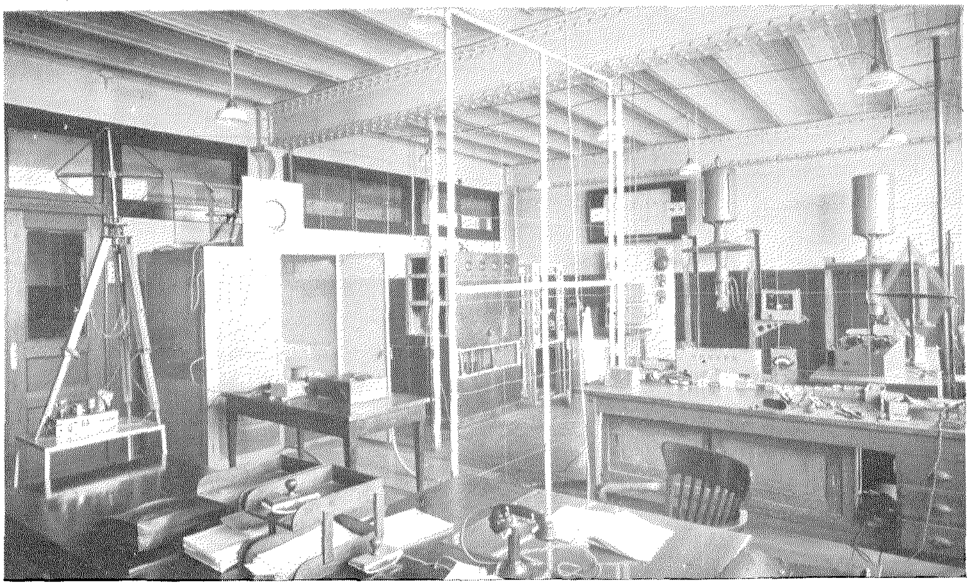
About twenty terminal equipments for power line carrier telephone systems have been supplied by the Nippon Electric Company during the year to several power companies. The systems employ different frequencies for opposite directions of traffic and the carrier frequencies are not suppressed. In addition to the stability of performance achieved by an automatic volume control, much higher quality of transmission has been obtained by the use of greatly improved filters.

Power Transmission

In the field of underground power cable, the greatest interest is directed to transmission at the highest voltages. To this end there have been put forward in the past few years various designs which permit a more economical utilisation of material at the expense of a more severe stressing of its electrical properties. This is rendered feasible by the ensured maintenance of a minimum fluid pressure on the impregnated paper dielectric. The sheath thus becomes involved in a new function while the simplicity of the normal type of solid core cable is sacrificed.

At the higher voltages the employment of these pressure devices has hitherto been considered essential, but the upper limit to the economical employment of solid type cable promises to be raised by the development of internally compensated intersheath cables in which the maximum electrical stresses are reduced by the configuration adopted in the design.

In high voltage cables, progress has been made in achieving a greater compactness of the active dielectric by the selection of more suitable materials and by improved paper-lapping methods, by the elimination of adulterants such as oxidation and acid products as well as moisture, and by the reduction of the gaseous content of the cable through improved impregnation methods.



Radio Direction Finding Laboratory, Les Laboratoires Le Matériel Téléphonique.

The application of fluid pressure to cables has called attention to the need in special cases for barrier joints for preventing the migration of compound or limiting the pressures set up within the cable. The development of the "Styrene Joint" offers many advantages, both electrical and dimensional, over the more conventional type of stop-joint.

A "dry core" type of power cable working at high gas pressure has been proposed. This type of cable would to some extent bridge the gap between telephone and power cable practice and might find application in both fields.

Bell's 60th Anniversary in Japan

Early in June, 1936, the Japanese Institute of Telephone and Telegraph Engineers, allied with Teishinsho, held a convention and exhibition at the Mitsukoshi Department Store in Tokyo to celebrate the 60th Anniversary of Alexander Graham Bell's invention of the telephone. During the course of the exhibition Mr. T. Kajii, Director General of Teishinsho, gave a popular lecture on the history of Japan's communication systems. In addition, Teishinsho and many of the communication manufacturing companies supplied equipments for public demonstration.

Ultra-Short Wave Radio Landing Beam

The C. Lorenz-A.G. Radio Beacon Guide Beam System

By R. ELSNER AND E. KRAMAR,
C. Lorenz-A.G., Berlin-Tempelhof, Germany

WITH modern methods of aerial navigation and growing air traffic density, electrical landing facilities are of constantly increasing importance. Under unfavorable weather conditions they are indispensable to successful aircraft operation.

Preliminary to a description of the essential advantages of the C. Lorenz-A.G. ultra-short wave system, it may be stated that basically, it provides radio telegraph reception indicating the approach path to the airport and, similarly, two distance markers governing the landing process. When developing the system, the guiding principle was to employ radio only for such purposes as could not be accomplished by other means, and at the same time provide a receiver which would be electrically independent of that used for communication purposes, thus reducing the manipulation on board to a minimum. In view of these considerations and with due regard to factors such as interference from landing beacons of neighboring airports, the operating frequency had to be chosen. Because of their definitely determined operating ranges, only frequencies over 30 megacycles could be considered, both for the radio beacon itself and for the marker beacons.

The direction of approach in the C. Lorenz-A.G. system is based on the beacon principle, giving side or boundary indication of the landing path; and, also, at two points along this path, signals serving as distance markers, and indicat-

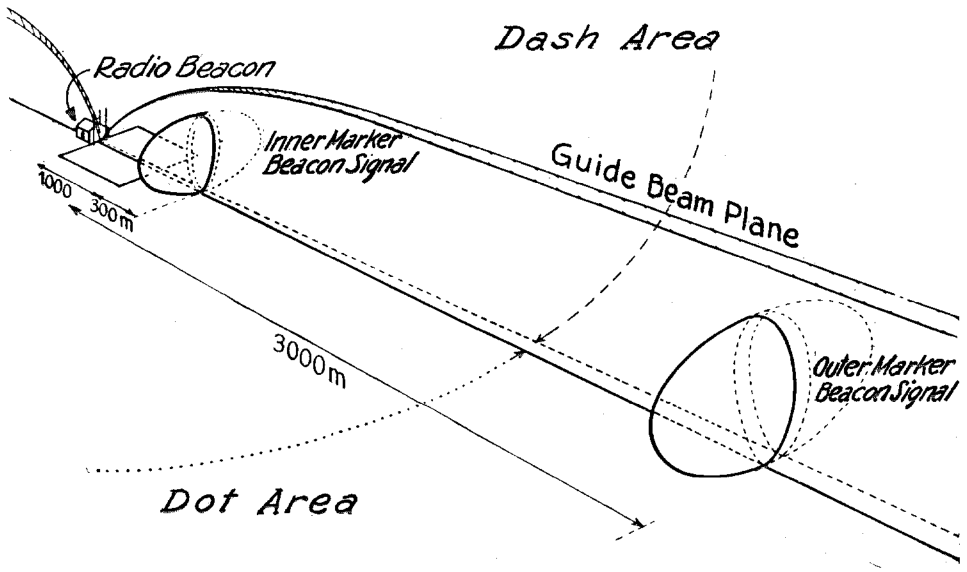


Fig. 1—Guide Beam Landing Radio Beacon—Lorenz System.

ing to the pilot the distance of the machine from the landing field (Fig. 1).

Ultra-short waves, with their lines of constant field strength, may be utilized under specific circumstances in vertical navigation as electrical landing curves; but they have not been thus applied in Germany during the last part of the landing process despite the fact that experiments have indicated their practicability under certain conditions. Difficulties in their application lie mainly in the fact that the course of their curve does not correspond to the natural glide path. These difficulties have been overcome with the help of clockwork regulating instruments which reshape the normal indication obtained by means of the beam into a straight glide path. The experimentally tested glide path (Gleitweg) process, with due regard to certain attendant circumstances, can be utilized as, for example, in Switzerland, where the glide path is followed down within a few meters from the ground.

The equipment of the ground station is the same, irrespective of whether the method of electrical vertical navigation is employed or that at present utilized in Germany, viz., of landing at a constant rate of descent (Fig. 2).

Outline of the Approach and Landing Process in the C. Lorenz-A.G. Ultra-Short Wave Guiding Beam System

If, in consequence of poor visibility due to fog or other conditions, landing by means of a radio beacon beam is necessary, the pilot guides his machine to the vicinity of the airport (a zone of approximately 30 km. radius) by existing means of direction finding or homing. By means of the tone modulated signals radiated by the main beacon, he reaches the approach path marked by this beacon. For the reception of the beacon signals an automatically operating receiver is used, furnishing the pilot with both aural and visual indication of the position in the horizontal plane of the machine with respect to the guiding beam of the radio beacon. The approach path sector, as is well known, is defined by the intersection of two radiation diagrams produced by the alternate operation of two reflector dipoles (Fig. 3). Should the airplane be outside of this approach path, short dots are heard on the port side, or dashes on the starboard side. Divergencies off the course are again indicated both aurally and visually (Fig. 4). By intermittent deflections to left or right of the received signal, the indicating instrument shows the direction in which the pilot should steer his machine in order to reach the approach path in which the (complementary) signals, by merging into one another, become a continuous note. At the moment when the continuous note is reached, the direction indicator comes to rest and indicates to the pilot that he should maintain his course for a safe landing at his destination.

During the approach, the pilot gradually decreases his height to about 200 meters. At about 3 km. from the boundary of the landing field when reaching the outer marker beacon signal, lamp ("V") on the left-hand side of the visual indicator apparatus lights up and, at the same time, a deep note (700 p : s) is heard in the headphones. The pilot then throttles back and gliding down at an approximately constant rate of descent reaches the admissible minimum height at the inner marker beacon. The inner marker beacon signal is given at a distance of 0.3 km. from the boundary of the landing field—a few seconds before the machine reaches this boundary—and is conveyed to the pilot by a rhythmic short-keyed high note as well as by the lighting of the right-hand lamp H in the visual indicator equipment. The pilot now knows that there are no obstacles to his flight in the final section of the landing path and can, consequently, further reduce the height of flight in order that he may bring his machine down safely even when ground visibility is at its worst.

This briefly described landing method is used to a very great extent in Central European traffic. It consists in the determination of the approach course to the airport as well as in the transmission of signals which mark two important distances from the boundary of the landing field and which are involved in the process of landing. This landing method, employing landing beacon beams of the type used in the C. Lorenz-A.G. ultra-short wave system, is being increasingly applied in European air traffic.

The Design of the C. Lorenz-A.G. System

The Lorenz system of navigation necessitates a "ground station" at the airport, and the installa-

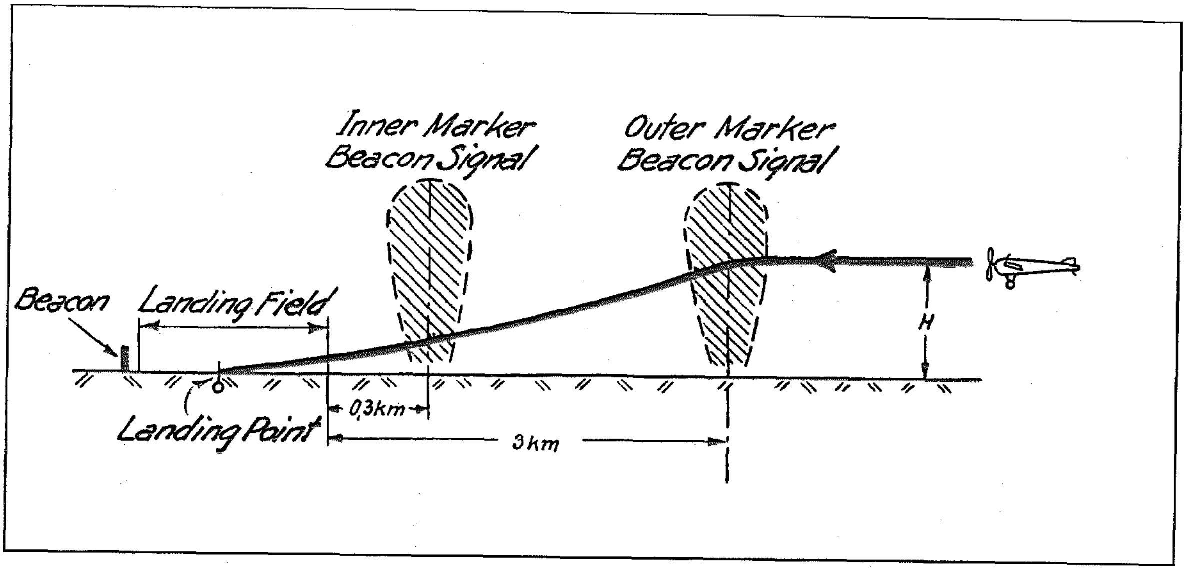


Fig. 2—Schematic Arrangements of Landing Method in the C. Lorenz-A.G. Ultra-Short Wave Guide Beam Process.

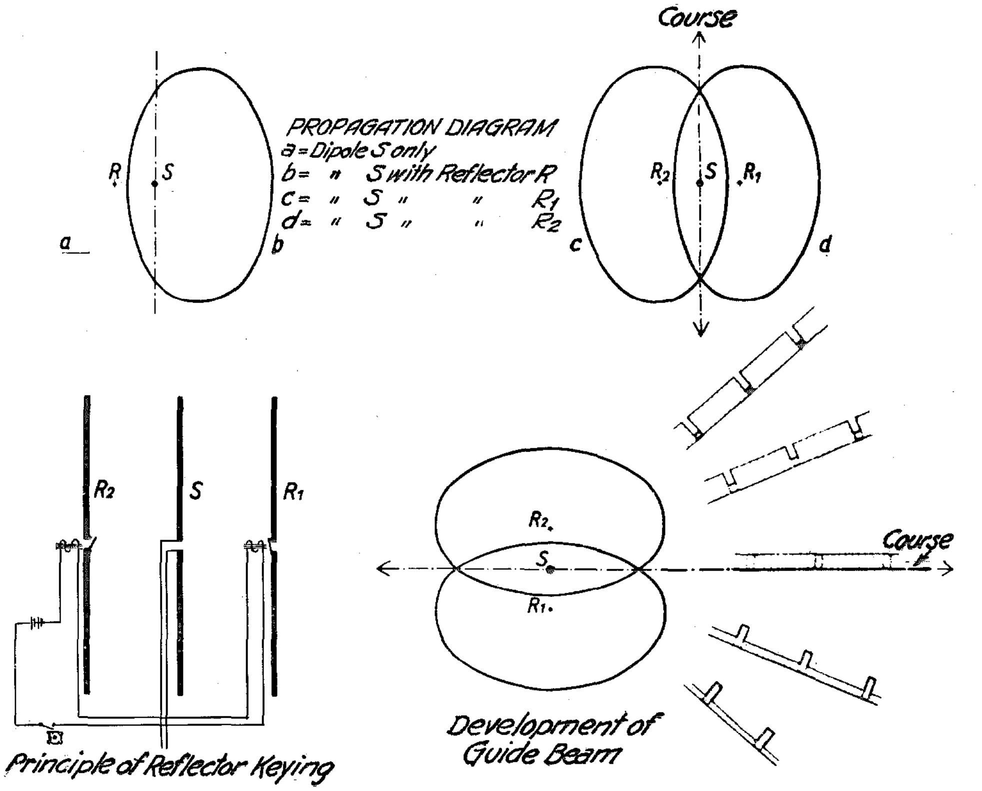


Fig. 3—Illustration of the Guide Beam Zone.

tion of complementary receiving equipment ("plane station") in the airplane. For the ground station, central and fully automatic remote control both of the main transmitter and of the marker transmitters is provided. On the control panel, indication of the correct working of all three beacons is provided by means of similar revertive signals. The airplane receiving set is fully automatic in operation; it employs a minimum number of valves, is simple in design, and is light in weight. The necessary range is ensured by an adequate design of the ground station.

The ground equipment comprises a 500 watt guide beam beacon transmitter together with two or four small (5 watt) transmitters for the transmission of the "signals," according to whether one or two directions of approach flight are provided for (Fig. 5). The remote control of all transmitters takes place from a central control set ("control station") where, also, the revertive signal impulses for the supervision of traffic are made perceptible. All the transmitters are crystal controlled, operating on ultra-short waves and are designed for all mains operation. They are supervised in every phase of operation by means of visual and audible indications at the "control station." These measures doubly ensure the operation of every component part and guarantee a high degree of reliability for the system as a whole. They represent an absolute necessity for purposes of landing when visibility is bad.

(*a*) *The Radio Main Beacon Transmitter.* The requirements for this transmitter emerge from the physical bases of the landing method employed in the C. Lorenz-A.G. system. In addition to necessary constancy of radiation to provide constant field strength, the navigational significance of "beacon" radiation requires a high frequency stability as well as an adequately constant degree of modulation. Fundamentally, the circuit employs a crystal controlled oscillator stage from which the operating frequency ($f_B = 33.3$ megacycles) is amplified in four stages and, by means of the grid potential, the fourth stage is tone modulated. The transmitter is shown in Fig. 6*a*, where the disposition of the constituent equipment may be seen. In the lower part are housed the component aggregates for the power supply which, in addition to the ventilation devices for the transmitter container, also include the high and low tension rectifiers (selenium rectifiers and smoothing devices). Above this equipment are the component sections intended for the circuit distribution of the feed potentials including all the associated testing instruments and also the auxiliary devices used for modulation of the operating frequency and for the keying of the associated radiation system. Near the cast iron transmitter container, a quick acting voltage regulator operates from the local 3-phase mains regulated to ±0.5%. The beacon transmitter is installed in a specially provided, small brick building from which feeder and keying lines connect to the radiator system. The latter consists of an energizing dipole, which is fed from the transmitter terminal stage, and on both sides of which a reflector dipole is placed at an interval of $\lambda/4$. These, with the energizing dipole, are in a plane vertical to the guide beam plane and are fed by radiation coupling. The complete vertical radiation system is mounted on

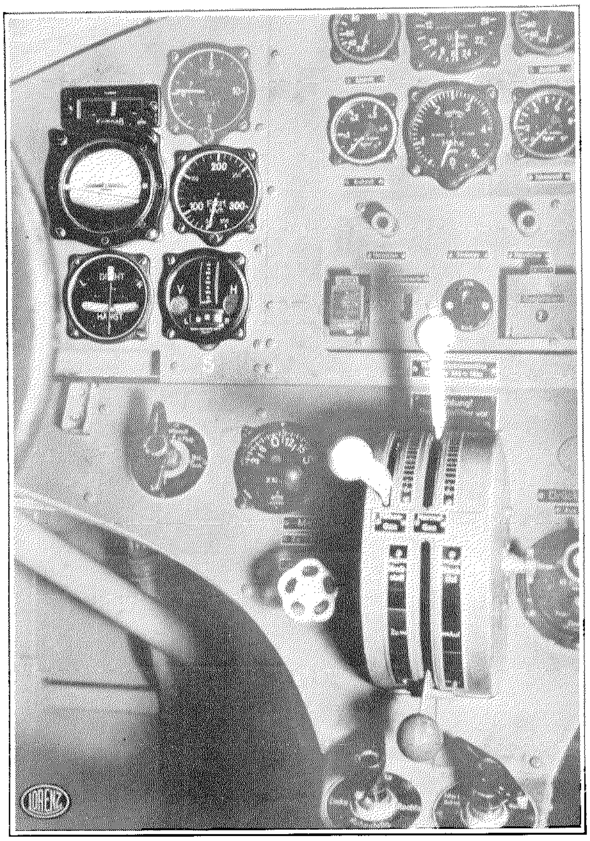


Fig. 4—Visual Indicator Equipment Mounted on the Dashboard of a Commercial Airplane in Conjunction with Other Navigational Instruments.

stiffened wooden masts erected directly in front of the beacon building (Fig. 6*b*).

(*b*) *The marker beacon (signal) transmitters* function on an operating frequency of $f_E = 38.0$ megacycles and differ, from a high frequency aspect, from the beacon transmitter only in the number of amplifier stages (Fig. 7). According to the purpose for which they are to be used, the modulation frequency is either 700 p : s (for the outer marker beacon signal) or 1,700 p : s (for the inner marker beacon signal); the allocated keying series are shown in Fig. 8. The current supply of the signal transmitters is arranged for mains connection, the anode and initial grid potential being obtained by means of dry rectifiers. The transmitter itself is of a rigid and concentrated design and includes complete mounted keying and revertive signal equipment as well as all the accessories.

With regard to all the transmitters, the following may be said: in principle, importance is attached to easy manipulation and control of the correct operation of all the component apparatus. In addition to being remotely controlled all transmitters can be put into operation locally by means of switching devices which are conveniently accessible on the transmitter front panel. In practical operation they are normally connected and disconnected from the "control station" which is generally installed in the control tower of the airport.

(*c*) *Transmitter Radiation Fields.* The arrangement of the radiation fields, in relation one to another, is illustrated in Fig. 1. It shows how the approach path sector—produced as a result of the keying rhythm of the main transmitter by the alternating operation of the reflector dipole—is intersected at two characteristic points by the two radiation fields of the signal transmitter.

The transmission of the marker signals necessary to the landing process is effected by the upwardly directed, horizontal dipoles of the signal transmitters. The correct time period of reception (so-called wall strength) of the marker signals during flight is obtained by influencing in a simple way the radiation field of the horizontal

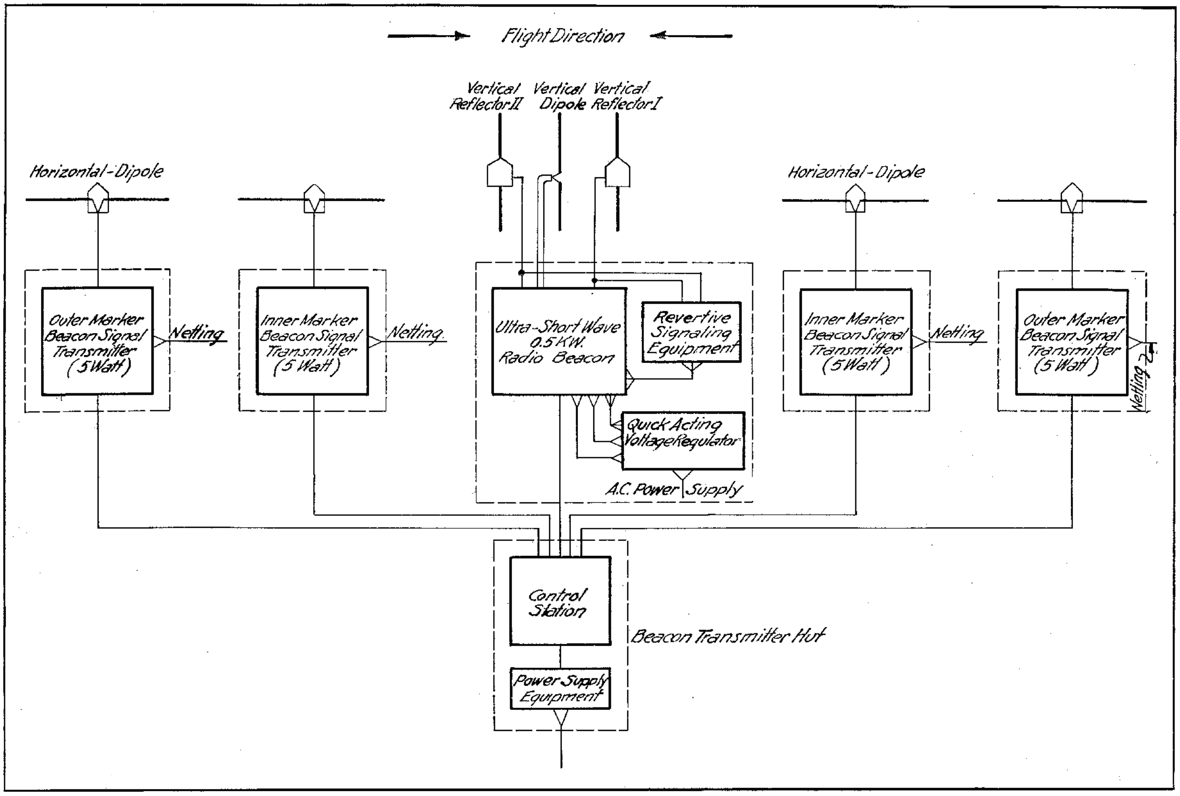

Flight Direction
Vertical Reflector II
Vertical Dipole
Vertical Reflector I
Horizontal-Dipole
Horizontal-Dipole
Outer Marker Beacon Signal Transmitter (5 Watt)
Netting
Inner Marker Beacon Signal Transmitter (5 Watt)
Netting.
Ultra-Short Wave 0.5 KW. Radio Beacon
Revertive Signaling Equipment
Quick Acting Voltage Regulator
A.C. Power Supply
Inner Marker Beacon Signal Transmitter (5 Watt)
Netting
Outer Marker Beacon Signal Transmitter (5 Watt)
Netting
Control Station
Beacon Transmitter Hut
Power Supply Equipment

Fig. 5—Plan of a Complete Ultra-Short Wave Radio Beacon Landing System (C. Lorenz-A.G. System).

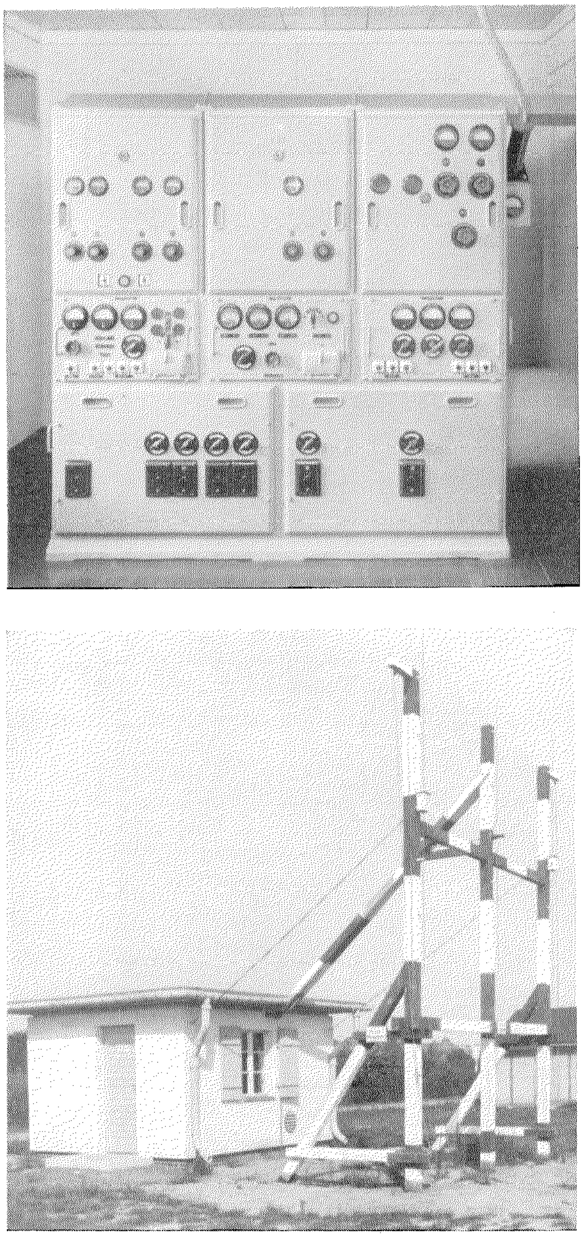


Fig. 6—Radio Beacon Guide Beam Transmitter. (a) The Beacon Transmitter Inside the Protecting Hut. (b) The Hut with Complete Radiation System.

dipoles. By a suitable arrangement of a wire netting, which may be regarded as a reflecting surface, it is possible with the dipole placed at about $\lambda/2$ above the surface to attain the required vertical radiation, the separation of the dipole from the reflection surface being considerably less at its center because of the curvature of the netting (Figs. 9*a* and 9*b*). Fig. 10 shows the characteristic curve of this vertical radiation. The marker transmitter is housed in a wooden hut below the netting.

Operation of Ground Station. As already mentioned, the easy supervision at any time of the operation of all component parts is of exceptional importance in view of the purpose of the system. This is accomplished by means of visual and audible signals on the same apparatus from which the switching is done. The "control station" is accordingly the nucleus of the navigational system and, at the same time, the agency that regulates and supervises the manifold switching processes pertaining to traffic operations. The operating control of all transmitters is based on the revertive signal process: the mains voltage and demodulated antenna currents from all transmitters are carried back to, and suitably indicated at, the control station. The same operating supervision directly at the individual transmitters themselves is also provided.

In practice all transmitters are put in operation by means of one main switch on the remote control panel.

When planning the ground station the direction of approach to the airport for (perfect) landing is determined with due regard to the direction of the wind.

The main switch on the remote control panel with its corresponding control contacts indicated in color on the panel is so arranged that by switching either to one or the other side the appropriate marker beacons for that particular direction of approach are brought into operation. Simultaneously, by the same means, the keying of the beacon transmitter is adjusted in a manner such that dots are always transmitted to the port side of the course. These measures obviously add to the degree of safety in the carrying out of this navigation process.

On the front panel of the "control station" (Fig. 11) colored signal lamps show the presence of mains voltages and meters show that the transmitters are actually working the needles of these meters, swinging in the keying rhythm of each particular transmitter. Along with these purely visual signals, arrangements may be made for listening to the different keying signals and modulation frequencies by means of telephone control. Furthermore, any trouble is indicated acoustically by the operation of an alarm whistle

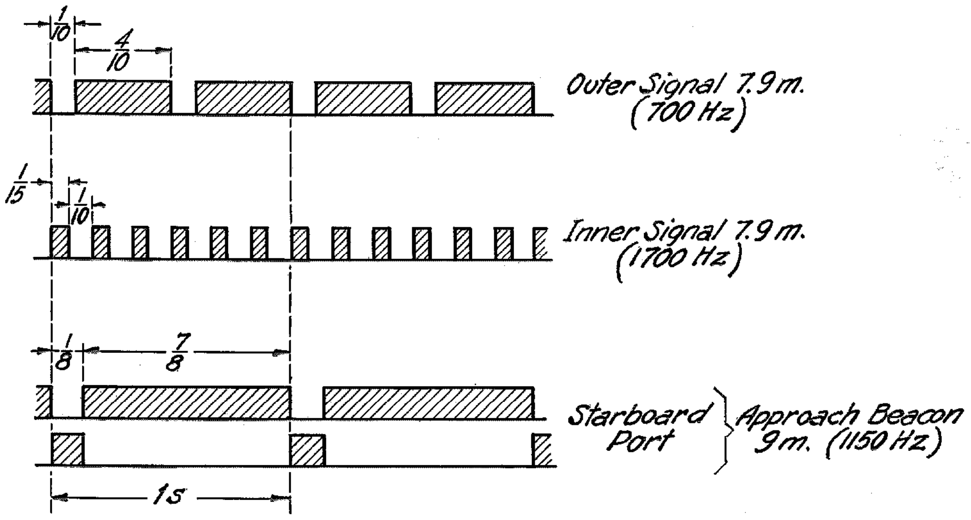


Fig. 7—Keying Sequence.

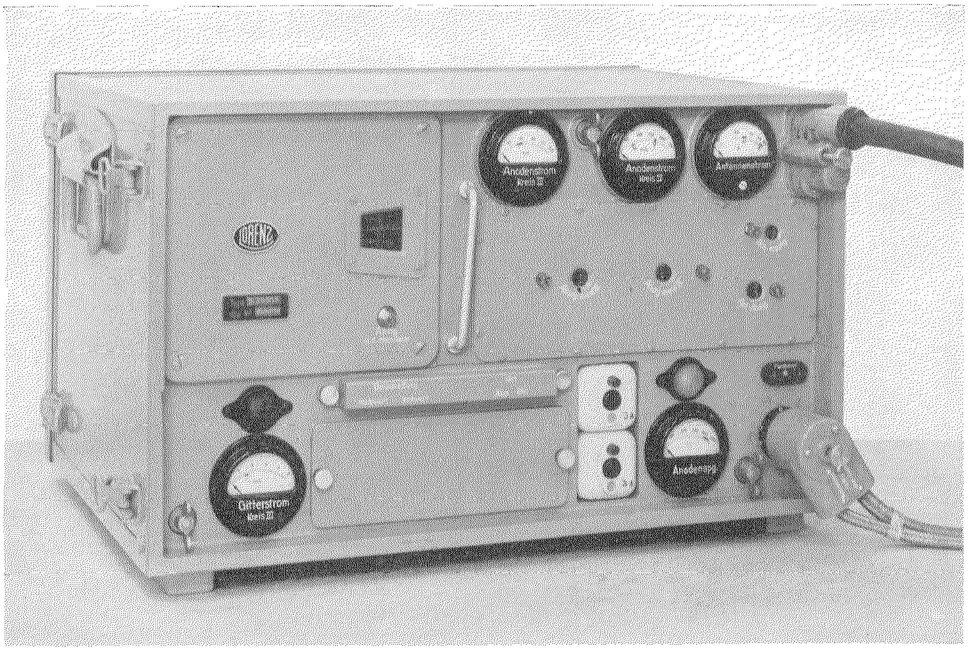


Fig. 8—"Signal Transmitter" with Mains and Antenna Cable Connected.

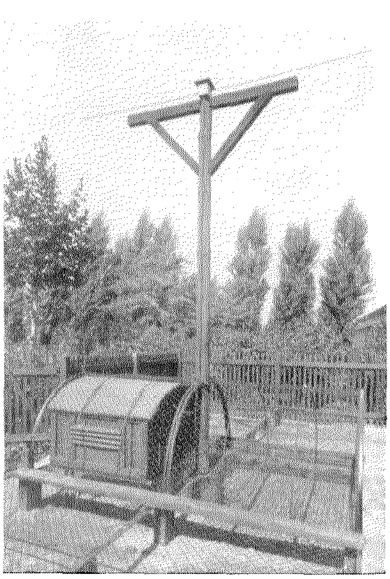


Fig. 9a—Complete Signal Transmitter System.

and visually by the warning signal of a drop indicator. In addition, simple means are provided for the quick testing of all control and revertive signal lines to all transmitters.

Revertive signal equipment which, in particular, is intended for checking the dipole relays and which is mounted near the transmission line, is an additional means of supervising locally the beacon transmitter.

The plan in Fig. 5 shows the fundamental design of the ground station in its electrical association with the central control and supervisory stations provided for two directions of flight and, correspondingly, four signal transmitters. The spacing of the complete ground system is dependent on the position of the airport and, above all, upon the immediately surrounding conditions. It is, therefore, determined as occasion arises.

The Airplane Receiving System (Airplane Set) for Landing Purposes. The airplane receiving system serves to receive the high frequency signals which follow one another successively on the

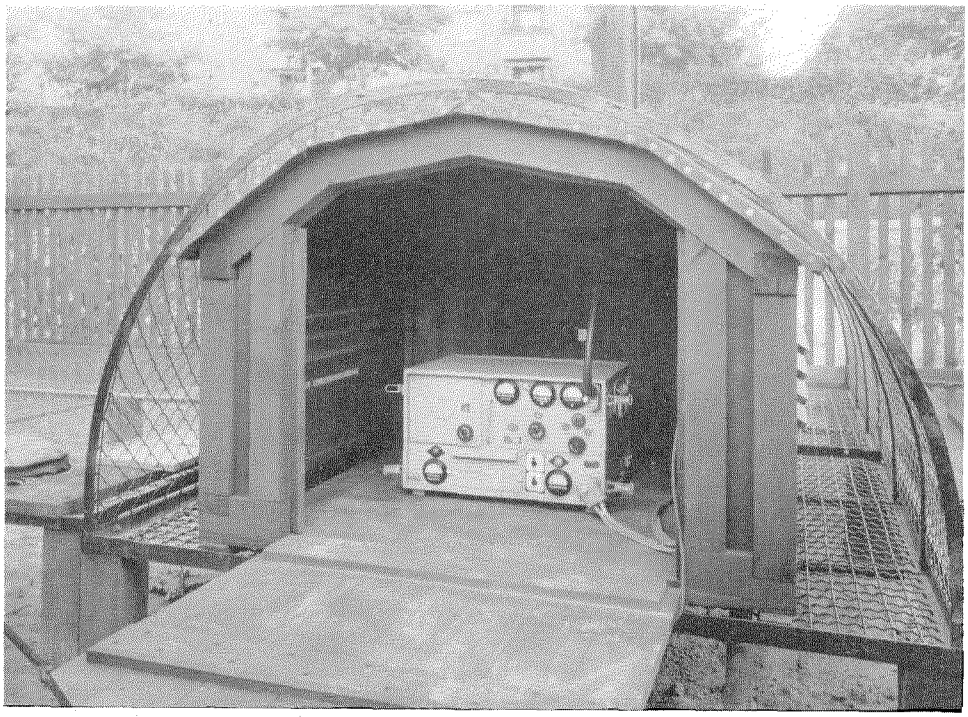


Fig. 9b—Signal Transmitter Erected in Wooden Hut under the Reflector Arch.

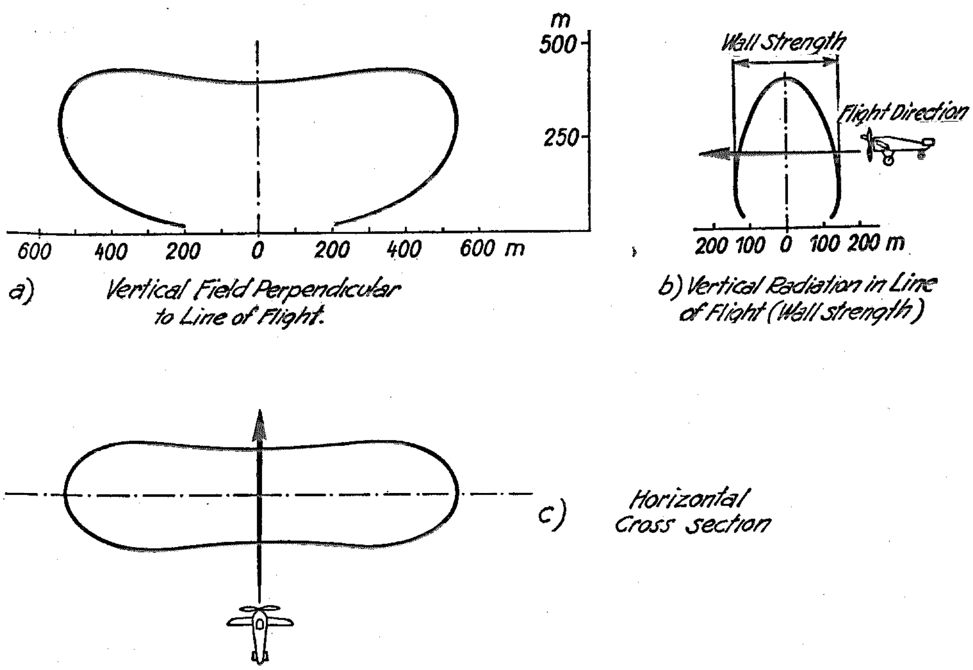

m
500
250
600 400 200 0 200 400 600 m
a) Vertical Field Perpendicular to Line of Flight.
Wall Strength
Flight Direction
200 100 0 100 200 m
b) Vertical Radiation in Line of Flight (Wall strength)
c) Horizontal Cross section

Fig. 10—Radiation Characteristic Curve of the Signal Transmitter.

principle of the landing method. It consists of the receiver and two associated receiving antennae. The apparatus for the pick-up of the beacon frequency is a simple amplifier which has a high frequency amplifier stage, a detector, and a low frequency amplifier. Automatic amplifier regulation maintains the sound volume fluctuations in the headphones (Fig. 12) within admissible limits even with very considerable field strength alterations during flight. A special detector, mounted in its own metal container, is provided for the reception of the marker beacon signals. It retransmits the demodulated tone frequencies of the outer marker beacon signals to the low frequency amplifier of the beacon receiver. Here, therefore, all three modulation notes of the ground transmitter are amplified. A filter network (frequency filter), adjusted to the existing tone frequency, filters the modulation frequencies of the marker signal transmitter (700 p : s or 1,700 p : s, respectively) and passes these low frequency voltages on to the visual indicator apparatus. During the approach to the radio

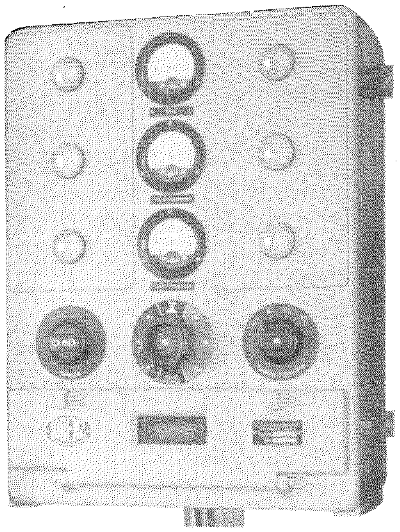


Fig. 11—The "Control Station."

beacon, an approximate idea of its distance is obtained by means of a vertical indicator instrument which is in the visual indicator set and which is connected through a rectifier to the low frequency amplifier. The modulation frequency of the main beacon (1,150 p : s) governs the amplifier regulation as well as the indication of distance and divergence to the side. Special equipment, which is connected to the low frequency amplifier through a rectifying arrangement, and which is mounted horizontally in the instrument container of the visual indicator set, indicates divergences to the side and serves to clearly determine the course of the airplane. During flight, a switch mounted in the operating set on the dashboard of the airplane is placed in the "approach" position, and amplifier regulation is effected. (For the purpose of glide path landing—vertical navigation—this switch is thrown to "glide path" at the outer marker beacon signal, whereupon automatic amplitude regulation is disconnected.) The airplane battery provides the power supply for the receiving set and operates the converter; the latter supplies power for the filament lamps as well as the necessary voltage for the anode circuit of the amplifier. An example of a typical installation of an airplane set in an airplane of the "Deutschen Luft-Hansa" is shown in Fig. 13.

A vertical dipole about 90 cm. in length, connected through a suitable transformer to the receiver input, serves as an antenna for the 9 meter wave of the beacon transmitter (Fig. 14). A horizontal dipole consisting of two copper tubes about 1 meter in length is used for the reception of the marker signals. These copper tubes are fastened at an interval of about 5 cm. along the airplane and under the fuselage by means of streamlined supports, and are connected through a transformer to the detector. The complete airplane receiving equipment, accordingly, consists of the beacon receiver, which contains the common low frequency amplifier, the detector, and the frequency filter, as well as the battery box or a rotary converter. On the dashboard of the airplane is mounted the visual indicator set which includes the two instruments indicating the distance and the deviation from the course as well as the two signal lamps.

Ultra-Short Wave Landing Radio Beacons in the European Air Communications System

If it be recognized that adaptation of the requisite ultra-short waves to this landing procedure makes normal aircraft radio communication on medium waves for additional direction find-

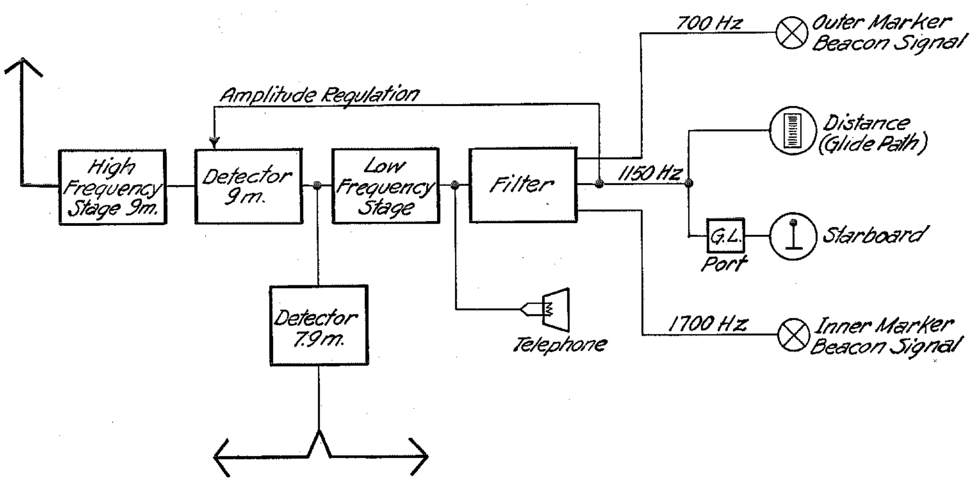


Fig. 12—Fundamental Circuit Diagram of the Airplane Set.

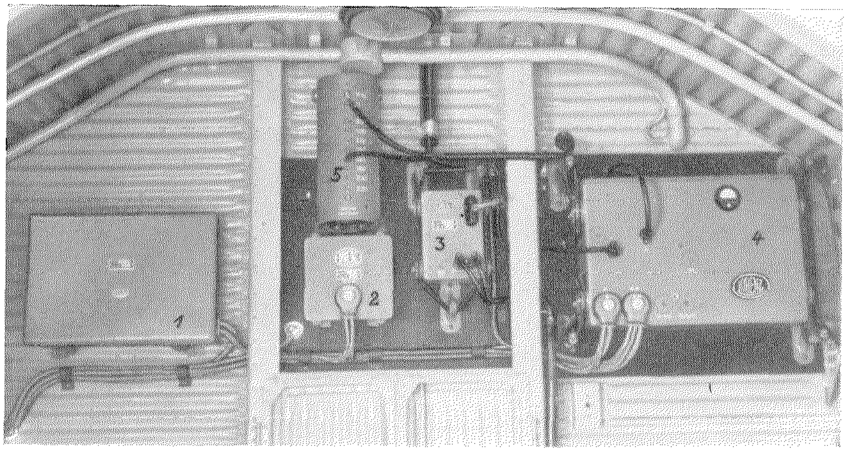


Fig. 13—Installation of a Receiving Set in Goods Carrying Airplanes Belonging to the Deutschen Lufthansa.

ing indication unnecessary and, also, that the normal airplane radio equipment is available for communication purposes during the last minutes prior to landing, a very essential advantage will have been achieved from the viewpoint of the service organization; this, quite apart from the fact that navigation on ultra-short waves is, in practice, not interfered with by simultaneous transmission and reception on medium waves. Furthermore, the ground equipment necessary for this landing method is designed so that it can, without difficulty, be introduced into existing ground station radio organizations. As early as the year 1932, under the direction of German Air Authorities, an experimental system was erected by C. Lorenz-A.G. for bad weather landing at the Berlin-Tempelhof airport and was demonstrated to those attending the International Air Service Conference in January, 1933. The next conference (Geneva, 1934), also the Meeting of Experts (Paris, November, 1933, and Warsaw, September, 1934), dealt with the improved design of this system and determined the operating frequency for the guide beam beacon as well as for the marker beacons, together with the associated modulation frequencies. These decisions and further practical experience led, during the last two years, to a rapid extension of the landing radio network in Germany and, from time to time, other European countries have adopted it. Today, the following German state airports are equipped with radio landing systems: Berlin, Breslau, Danzig, Leipzig, Frankfurt a/M., Hamburg, Hannover, Köln, Königsberg, München, Nürnberg, Stettin, and Stuttgart. Amongst foreign airports, the following already have complete sets: London (three radio landing systems), Milan, Paris, Stockholm, Warsaw, Vienna, and Zürich; similarly, Japan and Russia.

These radio landing systems are in preparation for Budapest, Prague, Rome, Venice, as also for Poland, Australia, South Africa, and South America.

In view of the great significance of the air service in modern communications, the landing radio beacon offers security facilities which can no longer be disregarded. It is, in fact, fundamental to developments in the important branch of aeronautics pertaining to safety.

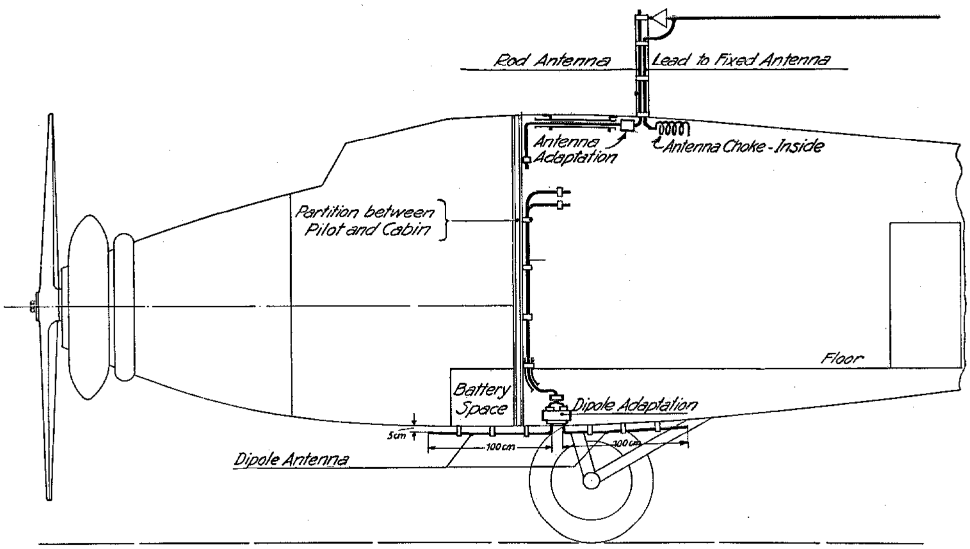


Fig. 14—The Antenna Arrangements of the Airplane Set.

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The following list of publications covers specific features and throws light on the development of this navigation system:

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2. E. Kramar: "Neuere Arbeiten auf dem Funkbakengebiete," (Recent developments in the radio beacon field), *Zeitschrift für Hochfrequenztechnik und Elektroakustik*, 1932, Vol. 39, page 88, (No. 3.)
3. Gloeckner: "Verfahren zur Erleichterung von Blindlandung," (Process to facilitate blind landing), *Zeitschrift für Flugtechnik und Motorluftschiffahrt*, 23, Year 1932, page 347.
4. E. Kramar: "Die Ultrakurzwellen-Funkbake," (The ultra-short wave radio beacon). *Elektrische Nachrichtentechnik*, 1932, No. 12, page 469.
5. E. Kramar: "Ein Beitrag zur Gleitwegblindlandung von Flugzeugen," (A contribution to the glide path blind landing of airplanes), *Elektrische Nachrichtentechnik*, 1933, No. 11, page 451.
6. E. Kramar: "A new Field of Application for Ultra-Short Waves," *Proceeding of the Institute of Radio Engineers*, Vol. 21, No. 11, November, 1933, page 1519.
7. Jung-Zaeper and E. Kramar: "Ein neuer Weg für Gleitwegbaken," (A new method for glide path beacons), *Luftwissen*, 1934, No. 4, page 92.
8. E. Kramar: "Ein Impulsanzeige-Verfahren für Funkbaken," (Impulse indicator process for radio beacons), *Elektrische Nachrichtentechnik*, 1934, No. 4, page 152.
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11. R. Elsner and E. Kramar: "Blindlandung von Luftfahrzeugen mittels Gleitwegbaken," (Blind landing of airplanes by means of glide path beacons), *Luftwissen*, 1935, No. 11.

Installation of Radio Distribution in the Beaujon Hospital, Paris

By G. MEUNIER
Le Matériel Téléphonique, Paris, France

THE Beaujon Hospital, erected at Clichy in 1934, with its twelve stories surmounted by its water reservoir, constitutes one of the highest buildings authorised to be built in the Paris area. It is also the most modern hospital. Perfectly ventilated, it faces south with a frontage of over 100 meters, and comprises on each floor four large common wards, disposed in rack-tooth style, where the private wards, resting, dressing, and operating chambers are located, as well as all other associated accessories of this immense "hospital-factory."

More than 1,000 beds are available. On each floor, terraces prolong each ward, thus enabling patients to remain for long periods in the sun and open air under the best possible hygienic conditions. The last two stories, more especially reserved for the treatment of consumptives, are entirely disposed in terraces to which access is obtained from the common and individual wards through large windows.

Annexes are located at the rear of the main building. They are equipped in an up-to-date manner for supplying power, light, and heat to all the buildings.

The dressing and operating rooms for special treatments (radiography and radiothermy) are provided with the most modern equipment.

The engineers of the "Poor Law Administration," who collaborated in creating this beautiful building, considered that above all, it had to be pleasant and agreeable both to patients and visitors. They endeavoured to eliminate all signs of sadness and did their utmost to achieve an atmosphere of cheerfulness. Air and light are abundant, and the view of Paris from the terraces is magnificient. The decorations of the wards, all different, are bright and pleasing.

It was appreciated that, unfortunately, highly pleasant surroundings will not prevent patients from becoming bored, and radio was resorted to as the best means of diversion. Several hospitals in France had already been equipped with radio, the initiative in furthering these installations having been due more to social groups than to the hospital managements. For a considerable time, patients themselves have had radio sets installed in nursing homes or sanatoriums. While sometimes quite rudimentary, these, nevertheless, afford the patient and his companions considerable pleasure.

Prior to the Beaujon Hospital installation, Le Matériel Téléphonique had carried out two installations in similar institutions: one for 50 head receivers at the Compiègne Hospital and another for 300 at the Colmar Hospital. The Beaujon Hospital project was of much greater magnitude, since 900 beds were to be provided with radio and 40 rest wards with loudspeakers having adjustable volume.

The decision to instal radio distribution in the Beaujon Hospital was made at a time when the erection of the building was well advanced; and, prior to approaching the firms capable of carrying out such an installation, an order had been placed with the general contractor for the installation of the radio distribution lines. These lines were composed of single-pair 0.65 mm. lead-covered telephone cable; therefore, their capacity was not adequate for distributing several programmes simultaneously or for operating the forty loudspeakers in the rest rooms with sufficient volume.

In view of the foregoing, it was decided to adopt distribution at low power, i.e., at a level allowing only for direct listening with head receivers. Loudspeakers connected in place of head receivers were provided with an amplifier fed directly from the power supply.

The distribution center was required to provide rediffusion of:

(1) Record music by means of two pick-ups,
(2) Musical retransmissions brought in directly by the P.T.T. from the different Paris theatres over telephone lines.
(3) Orchestral music or songs produced in a studio specially provided for this purpose in the hospital itself,
(4) Announcements and news items transmitted at the distributing apparatus itself.

Beaujon Hospital, Paris.

Equipment for meeting these different purposes was designed as follows:

The radio receiver consists of a Type 63, Le Matériel Téléphonique radio set, and is located on the second floor of the building. An antiparasite lead-in, a filtrostat system, and a single wire antenna are used.

This set can operate, either the power amplifiers or the control loudspeaker placed in the cabinet, thus permitting the selection of a station while another programme is being furnished to the patients.

The pick-up, Type 104–A, in an oil bath, the announcer's microphone of the diaphragm type, the studio microphone of the electrodynamic type, and the line from the theatrophone terminate in a special preamplifier.

The radio receiving set or the special preamplifier is connected to two No. 1212 amplifiers, each with two 2–A.3 tubes in push-pull, and capable of giving a modulated power of approximately 10 watts per amplifier.

A second group of two amplifiers, Type 1212, has been foreseen, as a spare group to replace the former, or for joint working in the event of an extension of the installation.

All the operations enabling the transmission of one of the five types of programmes contemplated are made by means of relays. A key and a lamp signal in the middle of the center panel of the cabinet correspond to each of these retransmissions.

To effect the retransmission of a given programme, it is only necessary to throw the corresponding key, with the result that the preceding programme is cut off and the connection between the power amplifiers and the distribution lines is momentarily interrupted, thus allowing the operator to adjust the retransmission without causing inconvenience to the patients. Upon restoring the key to its normal position, the connection between the amplifiers and the distribution lines is secured again.

Another key allows for the suppression of the other key positions without any programme being switched on. Finally, the announcer's microphone is operated by a special key: by operating it in one direction, the programme transmitted is suppressed and the announcer's microphone is connected; by operating it in the opposite direction, the preceding programme is again switched on.

The control loudspeaker can be used either on the distribution, i.e., after the amplifiers, or only on the radio receiving set for selecting a station. This loudspeaker, naturally, remains in circuit when changing the programme, the connection between the power amplifiers and the distribution lines being suppressed. On the other hand, the loudspeaker is automatically cut off when the key connecting the announcer's microphone is operated.

The control equipment utilises about ten relays of the automatic telephone type and is fed from alternating current (110 volts, 50 cycles) through a selenium rectifier. A lamp signal installed near the auditorium microphone indicates whether the latter is connected. Finally, a switch placed near this microphone enables the artists to cut off the transmission when their performance is finished.

The control loudspeaker is paralleled by an output power level indicator and can thus be cut out without losing the distribution control.

The whole equipment, mounted in a metal cabinet, has the operating and control apparatus described above placed on its face and includes two pick-ups on a desk-shaped shelf. The lower front portion contains a record filing cabinet; the lower rear houses the power amplifiers.

In planning the installation, much attention was paid to the detection of trouble on lines or distributing apparatus (head receivers and loudspeakers). It was almost impossible to equip the distribution circuits with fuses sensitive enough to cut out defective lines or apparatus automatically, particularly in the case of a partial short circuit or insulation defect. Hence the installation was divided into a certain number of sections, in principle one section per floor, each with an individual line to the operating cabinet.

Every line is controlled by a two-position key, permitting connection to the power amplifiers through a fuse or the cutting out of amplifiers, or else the closure of a circuit to an ohmmeter in the operating cabinet.

When a fuse is blown, indication is given to the

Head Receivers in Use.

operator by the lighting of a lamp corresponding to the defective circuit. It is then easy for him to throw the corresponding key so as to connect the line to the ohmmeter and thus determine whether the trouble is permanent or momentary. The electrician in charge of maintenance makes a careful test of the line by insulating successively at the cut-out boxes the different sections of the line, and thus rapidly locates the trouble.

If the trouble is not such as to blow the fuse but is interfering with the retransmission as a whole, it is easy, by connecting the lines one after the other to the ohmmeter, to locate the defective circuit, to momentarily insulate it, and to make a quick check without disturbing the rest of the installation.

Head receivers, meeting special requirements, were provided. They are very light in weight and do not press on the patients' heads; they are practically unbreakable and capable of being frequently disinfected in formaldehyde fumes. A volume control is readily accessible to the patient. Further, it was desirable that receivers might be detachable from the head band so that patients might hold them by hand. The existing L.M.T. model was modified to meet these requirements.

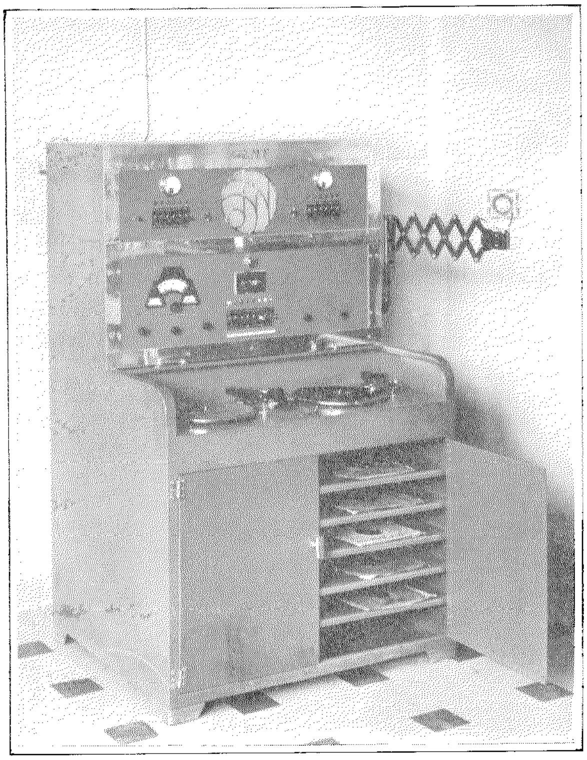
The ear pieces, in black moulded material, were replaced by white ones of a material similar to Polopaze. The volume control is of special design. It is housed in a white box of a material similar to the receivers and is connected to the middle part of the cord so that the patient may reach it quite easily.

A special cord was developed to resist formaldehyde fumes. It is equipped with a telephone type plug. The corresponding jack is contained in a metallic junction box which is white enamelled and is mounted on the wall for connection to the lead-covered cable.

A resistance shunts the line when the head receiver is removed, in order to avoid changes in volume with variation in load.

The loudspeakers installed in the rest rooms employ a 22 cm. diaphragm similar to that used in radio receiving sets and an amplifier with two stage triodes giving a power of approximately 1.5 watts.

In place of an input transformer, the grid is connected directly to the distribution line through a set of resistances and a potentiometer. The pilot lamp shows whether or not the apparatus is energised.



Programme Distribution Switchboard.

A tone control provides an especially suitable frequency curve. This was deemed necessary inasmuch as the rooms in which the loudspeakers are installed have highly unfavorable acoustic properties.

The Beaujon Hospital installation has the following characteristics:

Distribution at 4 to 5 volts approximately,
Power of the distributing center: 20 to 40 watts,
The simultaneous feeding of 500 to 900 head receivers and of 40 loudspeakers of 1.5 watts by means of amplifiers.

The distributing center is located in the library of the hospital. It is operated by the librarian, since the design is such that no special technical knowledge is required for operating the equipment.

This installation constitutes a standard for radio distribution in French hospitals. Several other institutions—sanatoriums, nursing homes, schools, etc.—are now contemplating the installation of a similar system.

Propagation Tests with Micro-Rays

By A. G. CLAVIER
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THIS paper relates to tests on propagation of micro-rays, which were carried out between experimental stations at St. Margaret's Bay (England) and Escalles (France) during the latter part of July and the beginning of August, 1935.

It had been known for some time that, on the frequency of 1,700 megacycles per second, which had been in use between the micro-ray stations at Lympne and St. Inglevert aerodromes, variations of signal strength were actually occurring, particularly during the hot days of the year. The tests here considered were undertaken in order to ascertain what influence a change of wavelength would produce on the amplitude and frequency of these fading phenomena.

The type of valves which was used did not differ from that in operation on the Lympne-St. Inglevert micro-ray link. Descriptions of these micro-ray valves have already been given.[1, 2, 3]

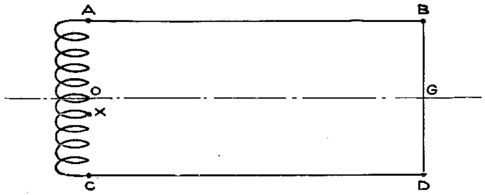

Fig. 1—Schematic Oscillating Circuit of a Micro-Ray Valve. AOC is the Oscillating Electrode and ABGDC, the External Circuit.

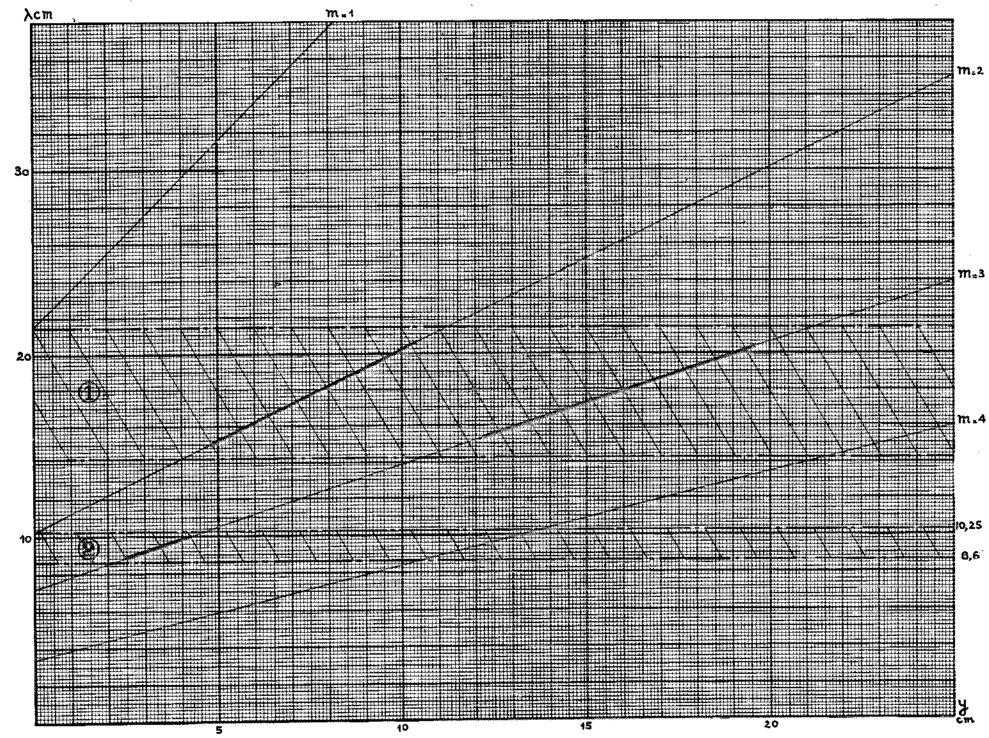

Fig. 2—Chart Showing Ranges of Wavelengths Produced by a Micro-Ray Valve (Type K). y is the Length of Transmission Line Leading to the Doublet and λ, the Wavelength in cm.

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[1] "Production and Utilisation of Micro-Rays," by A. G. Clavier, *Electrical Communication*, July, 1933.

[2] "The Anglo-French Micro-Ray Link between Lympne and St. Inglevert," by A. G. Clavier and L. C. Gallant, *Electrical Communication*, January, 1934.

[3] "Micro-Ray Communication," by W. L. McPherson and E. H. Ullrich, *Journal of the Institution of Electrical Engineers*, 1936, Vol. 78, No. 474.

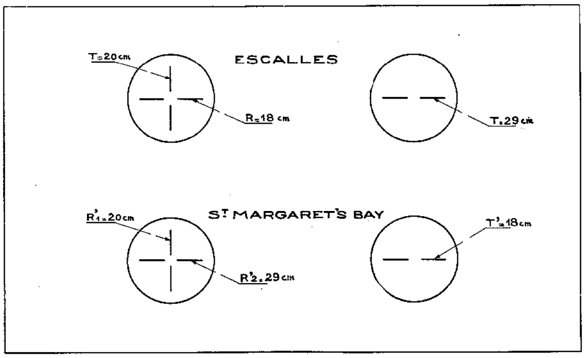

Fig. 3—Arrangement of Antennae for Propagation Tests.

They are made of three electrodes having a cylindrical symmetry, the tungsten filament being the axis of the structure, and a helicoidal oscillating electrode being provided with two wires connecting its extremities to the load circuit. The external electrode is a molybdenum cylinder, the axis of which coincides with the filament.

Since some of the components of micro-ray equipment are closely related to the frequency employed, it was decided to carry out the tests on a few frequencies of suitable separation. Valves and other components were then designed for these frequencies.

The main factor underlying the design of a micro-ray valve for a specified frequency range has been found to be the length of the wire of the oscillating electrode.[4] This can be shown by the following considerations.

The mechanism of electron movements inside the valve results in the production of a negative leakance along the wire of the oscillating electrode when suitable voltages are impressed on the electrodes. Thus, if we represent the oscillating circuit as in Fig. 1, it is made of two parts, one, *AOC*, being the oscillating electrode itself and the other, *ABGDC*, the external circuit. When stationary conditions are obtained, it can be assumed that *O* and *G* are nodal points for the oscillating voltage. Then call *V* the difference in

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[4] United States Patent 1,959,019, March 7, 1932.

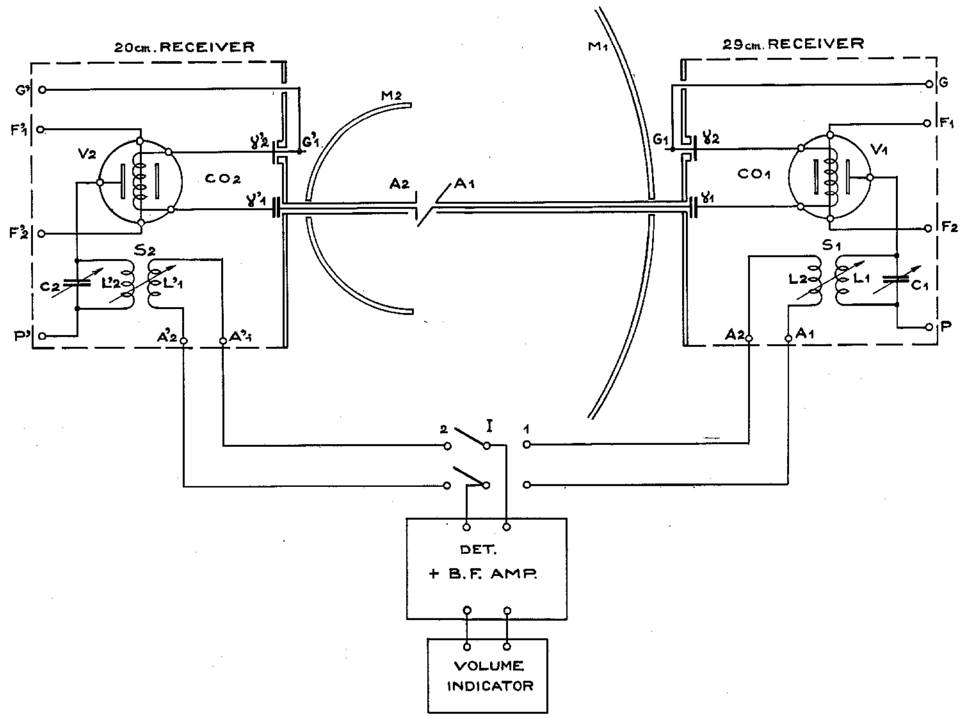

Fig. 4—Schematic of Receiving Equipment at St. Margaret's Bay.

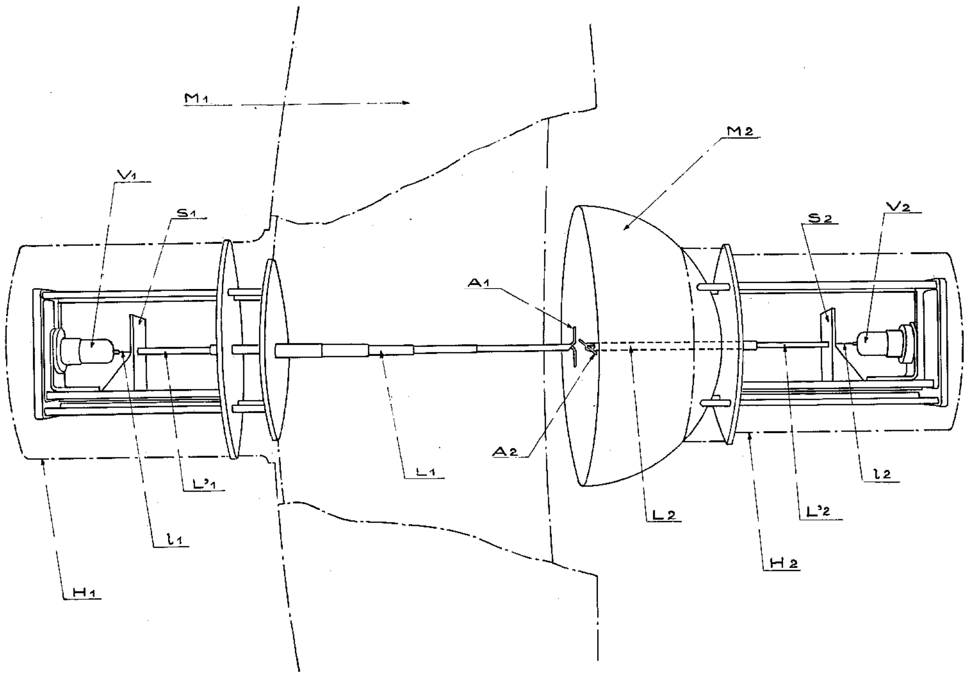

Fig. 5—Mounting of Two Receiving Valves on One Electro-Optical System at St. Margaret's Bay.
L_1 Transmission Line Leading from Antenna A_1 to Receiving Valve V_1 Behind the Paraboloidal Reflector M_1.
L_2 Transmission Line Leading from Antenna A_2 to Receiving Valve V_2 Behind the Hemispherical Reflector M_2.
H_1, H_2 Metal Coverings for Receiving Valve Assembly.

volts between any point X of the oscillating electrode and point O. Let i be the high-frequency current and r, l, g, c the usual resistance, inductance, leakance, and conductance coefficients per unit length. The voltage and current relationships may be expressed as follows:

$$-\frac{\partial V}{\partial x}=ri+l\frac{\partial i}{\partial t},$$

$$-\frac{\partial i}{\partial x}=gV+c\frac{\partial V}{\partial t}\cdot$$

From these equations the following general expression may be derived:

$$\frac{\partial^2 V}{\partial x^2}=\left(l\frac{\partial}{\partial t}+r\right)\left(c\frac{\partial}{\partial t}+g\right)V.$$

A solution of the form

$$V=V_0e^{j(\omega t-\beta x)},\quad \text{where}\quad j=\sqrt{-1},$$

is obtained when

$$lg+cr=0,$$

$$g=-\frac{cr}{l}$$

and

$$\beta^2=\omega^2cl\left(1+\frac{r^2}{l^2\omega^2}\right)\backsimeq\omega^2cl.$$

Taking β as the positive square root, the solution takes the following form:

$$V=V_1e^{j(\omega t-\beta x)}+V_2e^{j(\omega t+\beta x)}.$$

Assuming that point O is a nodal point for the voltages $V_1=-V_2$,

$$V=-2jV_1\sin\beta x\times e^{j\omega t}.$$

It is then found that

$$i=j\frac{2\beta V_1}{r+jl\omega}\cos\beta x\times e^{j\omega t}.$$

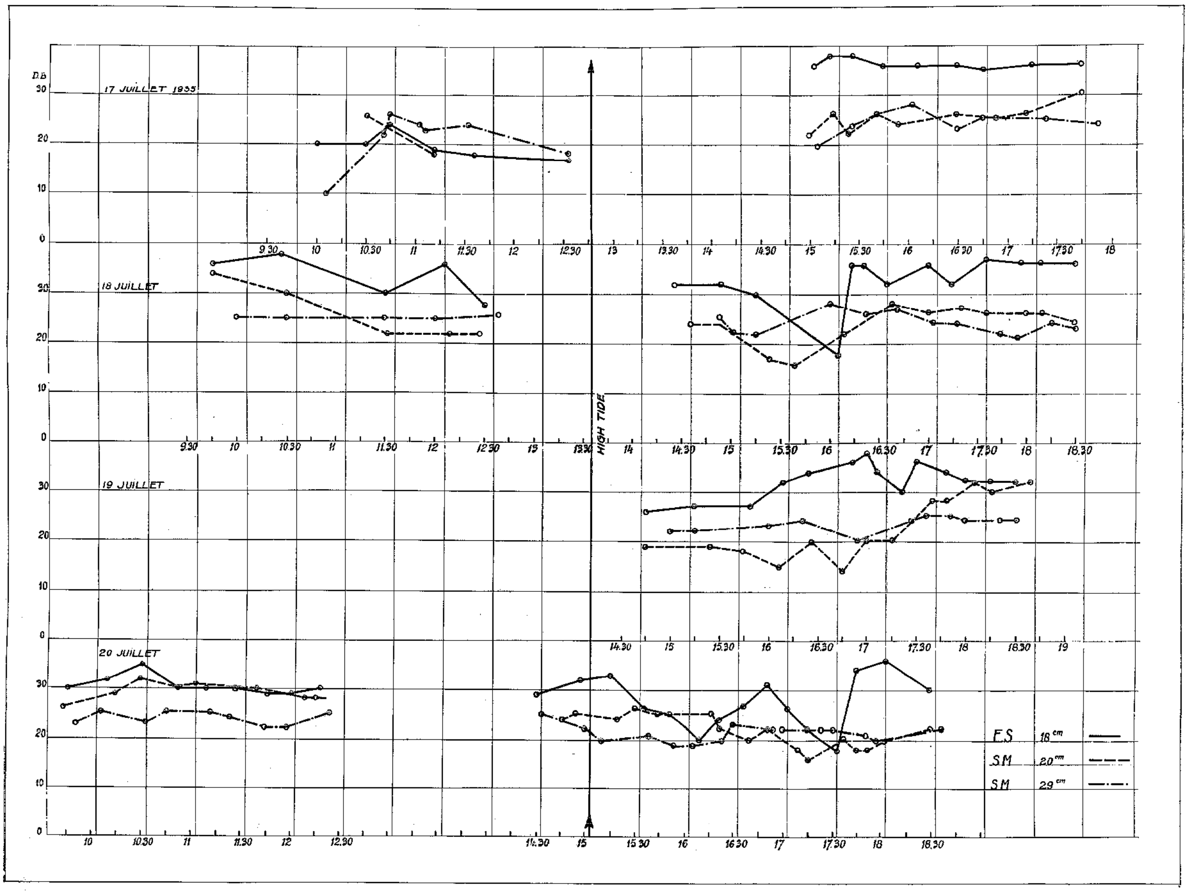

Fig. 6—Propagation Tests Between St. Margaret's Bay, England, and Escalles, France, Showing Signal Strength Above Noise Level.

Between two points X and X', symmetrical with respect to O, the voltage amplitude will be $-4jV_1 \sin \beta x$. It follows that the internal impedance between the extremities A and C of the electrode will be

$$Z_i = -\frac{2r}{\beta} tg\beta\frac{\Lambda}{2} - 2j\sqrt{\frac{l}{c}}\, tg\beta\frac{\Lambda}{2},$$

when Λ is used to designate the length of the wire of the oscillating electrode.

Now the external circuit can be considered as a transmission line AB, CD with a load R at the end due to radiating resistance.

Let

$$AB = CD = y;$$

then, if Z is the surge impedance of the transmission line, the input impedance is

$$Z_e = Z\frac{R\cos\beta' y - jZ\sin\beta' y}{Z\cos\beta' y - jR\sin\beta' y}.$$

We shall consider β' as approximately equal to β, which means that the propagation of the waves along the oscillating electrode and the transmission line will be assumed to be identical. Moreover, R will be assumed as relatively small compared with Z. For instance, in the case of two wires AB and CD 18 mm. apart, with a diameter of 2 mm., Z is approximately equal to 345 ohms and R to 8 ohms. In this case Z_e becomes approximately equal to

$$Z_e \backsimeq \frac{R}{\cos^2 \beta y} - jZtg\beta y.$$

The conditions for sustained oscillations may then be written

$$-\frac{2r}{\beta} tg\beta\frac{\Lambda}{2} + \frac{R}{\cos^2 \beta y} = 0,$$

$$2\sqrt{\frac{l}{c}}\, tg\beta\frac{\Lambda}{2} + \sqrt{\frac{l'}{c'}}\, tg\beta y = 0.$$

Considering only the simplified case when

$$\sqrt{\frac{l'}{c'}}=2\sqrt{\frac{l}{c}},$$

i.e., assuming there is no discontinuity in characteristic impedance on either side of AC, the condition which determines the wavelength is then

$$\lambda=\frac{\Lambda+2y}{m},$$

where m is any integer.

The condition for sustained oscillation is then

$$-\frac{r}{\beta}\sin\beta\Lambda+R=0.$$

This implies that $\sin\beta\Lambda>0$ and determines the ranges of possible wavelengths

$$\lambda>2\Lambda,$$

$$\Lambda>\lambda>\frac{2}{3}\Lambda,$$

$$\frac{\Lambda}{2}>\lambda>\frac{2}{5}\Lambda.$$

But the output delivered to the doublet BD is not constant throughout each possible range. This output can be calculated as a function of the circuit elements and is found to be

$$P=\frac{4V_1^2}{R}\frac{\sin^2 2\beta y}{1+\frac{Z^2}{4R^2}\sin^2 2\beta y}.$$

A maximum occurs when

$$2\beta y=(2k+1)\frac{\pi}{2},$$

in which

$$\beta=\frac{2\pi}{\lambda}=\frac{2\pi}{\frac{\Lambda+2y}{m}},$$

so that we obtain

$$\frac{8y}{\frac{\Lambda+2y}{m}}=2k+1,$$

where k is, like m, any integer.

It is thus possible, for a given length Λ of the electrode wire, to draw a chart, such as Fig. 2, which gives as a function of the length y of the transmission line the possible wavelengths which will be produced by the valve provided suitable electronic conditions for oscillations are obtained inside the structure.

Fig. 2 applies to a type of micro-ray valve for which $\Lambda=21.5$ cm. Region (2) corresponds to a very short wavelength, and the length y for which this would be obtained falls within the bulb of the valve. It is, therefore, region (1) which is usually employed.

This corresponds to $m=2$ and $k=1$, and the maximum output is obtained when

$$y=\frac{3\lambda}{8}=\frac{3\Lambda}{10},$$

$$\Lambda=\frac{5}{4}\lambda.$$

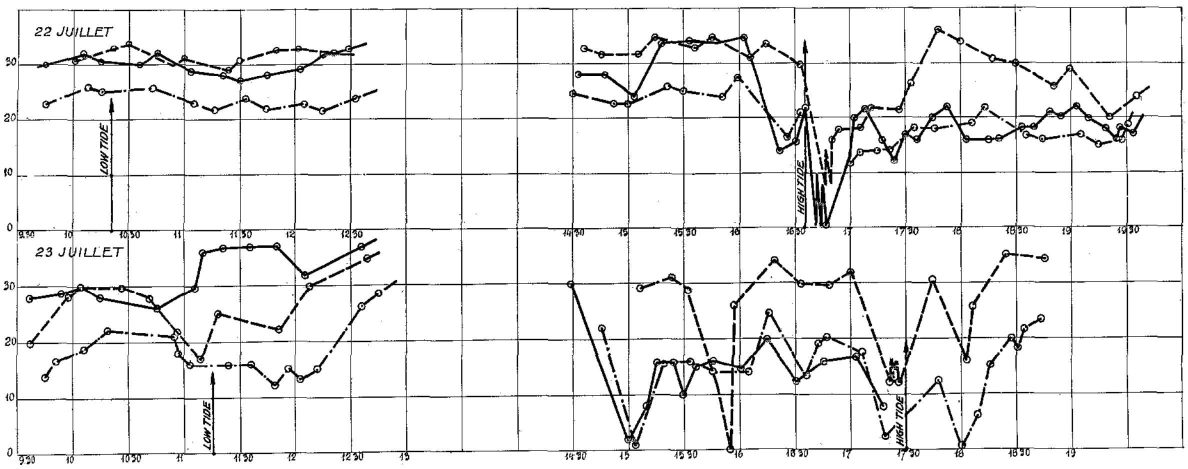

Fig. 7.

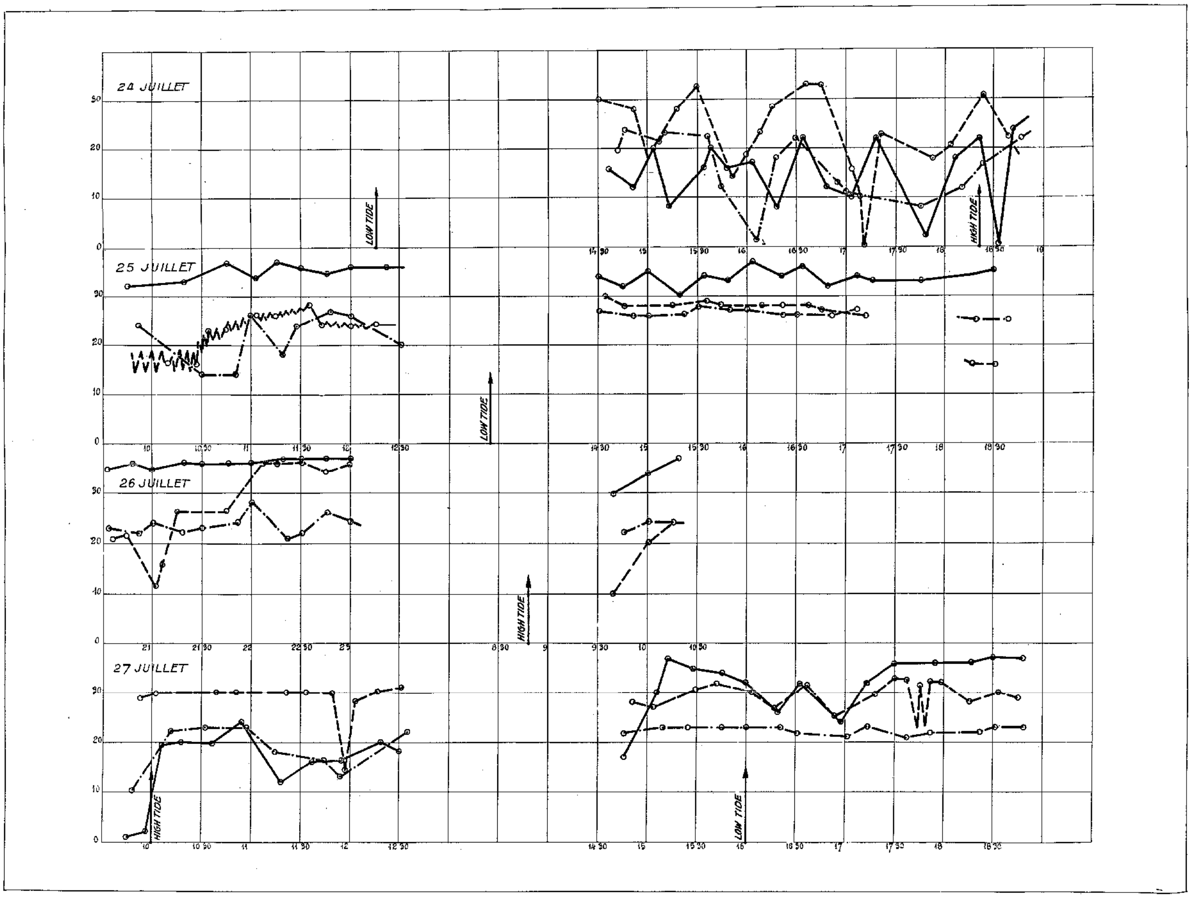

Fig. 8.

It must be remembered that this condition results from simplified theoretical considerations. But experiment gives the same order of magnitude and the same general sequence of oscillation frequencies.[4, 5]

For instance, valves designed for an optimum wavelength of

$$\frac{21.5\times4}{5}=17.2 \text{ cm.}$$

operated satisfactorily on that wavelength although a larger output was obtainable from the same valves on 19.4 cm., the length of the transmission line being then about 7 cm. Considering that this transmission line is far from possessing uniform properties as it must go through the glass of the bulb, the approximation obtained can be considered as satisfactory. Moreover, when applied to other valves designed for different wavelengths, the order of magnitude has always been found to be correct, and in certain cases the agreement between theory and practice proved to be quite satisfactory, particularly for longer wavelengths (up to 30 cm.). For these longer waves the diameter of the oscillating electrode was larger and the apparent internal characteristic impedance was probably nearer to the impedance of the external transmission line. It was thus found possible to manufacture sets of valves suitably designed for different wavelengths, ranging from 10 to 30 cm.

As already mentioned, the tests were carried out between St. Margaret's Bay and Escalles where there were available the two experimental stations which had been erected for the original demonstration of a telephone micro-ray, cross-channel link in March, 1931. Each experimental station was provided with two reflectors only and, in order to make simultaneous observations

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[5] "Vacuum Tubes as High-Frequency Oscillators," by M. J. Kelly and A. L. Samuel, *Bell System Technical Journal*, Vol. 14, January, 1935.

on several wavelengths, one reflector of each station was equipped with two valves. Fig. 3 shows what arrangement finally was decided on in the experiments under review.

Fig. 4 shows the schematic of the circuits used at St. Margaret's Bay on the receiving side. Two valves V_1 and V_2 were used, the first one as a receiver for the 29 cm. wavelength and the second one as a receiver for the 20 cm. wavelength. The corresponding antennae A_1 and A_2 were placed at the focal region of the electro-optical system and at right angles. The 29 cm. receiving valve was mounted behind the paraboloidal reflector in the usual way, but the 20 cm. receiving valve was mounted behind the hemispherical mirror M_2. As formerly indicated,[6] the radius of this hemispherical mirror should, for optimum operation, be equal to an integral number of half wavelengths. M_2, having a radius of 29 cm., was practically suitable for both wavelengths. A switching arrangement I was used to receive either on one wavelength or the other.

The second reflector, at St. Margaret's Bay, was used for transmission on 18 cm.

At Escalles, one reflector was used to transmit on 20 cm. and to receive on 18 cm., and the second reflector was used to transmit on 29 cm.

On the transmitting side, modulation was effected by applying voltages in a suitable ratio to the oscillating and reflecting electrodes of the transmitting valve in a way which has previously been explained.[1] Great care was taken to apply constant voltages on the valves.

This equipment proved to be quite satisfactory and no appreciable perturbations occurred between the two different receiving equipments. The system was entirely symmetrical and very easily protected against bad atmospheric conditions, as shown in Fig. 5.

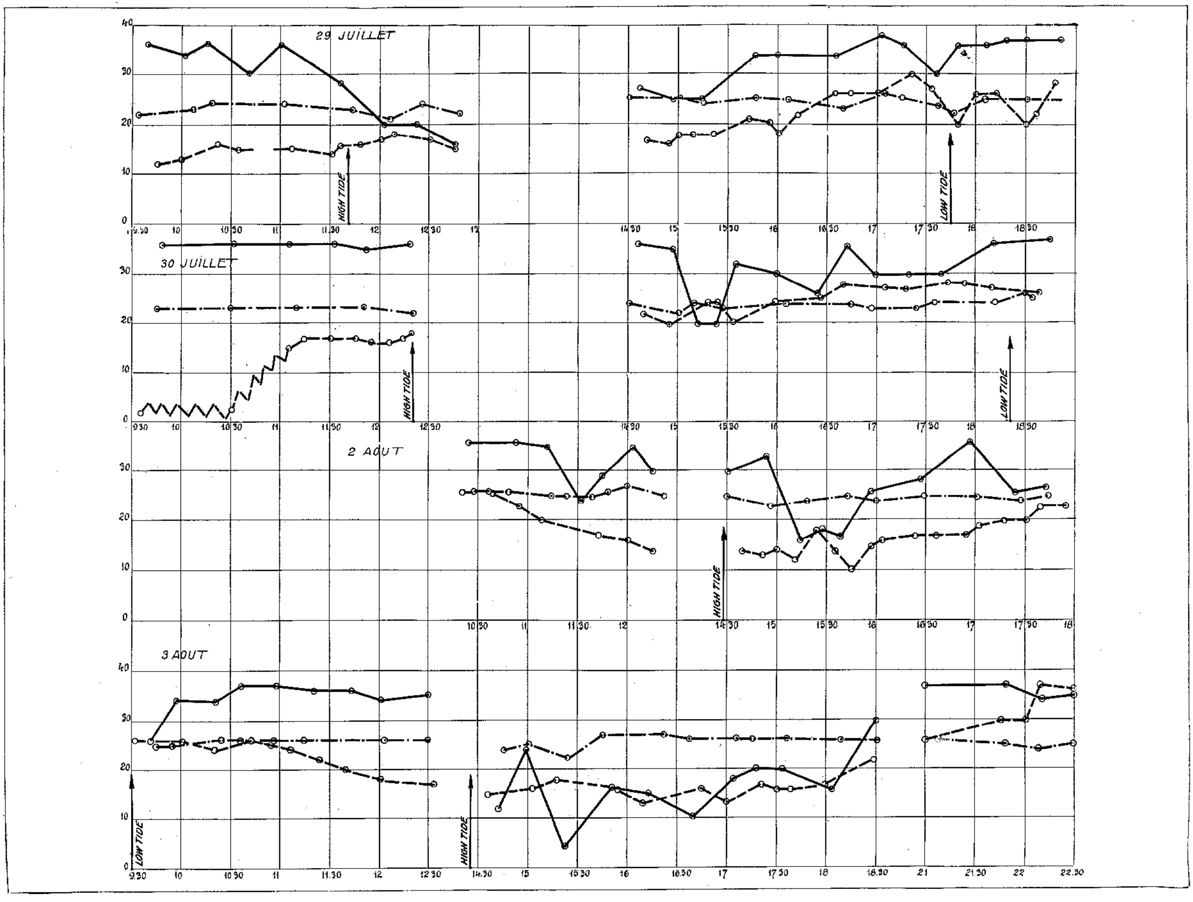

Fig. 9.

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[6] "Reflectors and Transmission Lines for Ultra-Short Waves," by R. H. Darbord, *L'Onde Électrique*, 1932, Vol. 11.

The method used for reception has previously been mentioned,[3] but further explanation may be of interest. When the micro-ray valve is suitably adjusted, it can perform two different functions simultaneously. First, it can be made to oscillate on a micro-ray frequency and, secondly, it can be used to produce an intermediate frequency, this second frequency bearing no numerical relation whatever with the micro-ray frequency. Consider, for instance, in Fig. 4, the 20 cm. receiving valve. In circuit CO_2, for suitable values of the voltages applied to the valve, an oscillation of micro-ray frequency F will be sustained, but in circuit $C_2L'_2$ there may also be produced oscillations of an entirely different frequency f. This frequency f is primarily conditioned by the circuit components C_2 and L'_2, but it also depends on the apparent capacity offered by the micro-ray valve. This capacity is, so to speak, shunted across condenser C_2.

This valve capacity has been found to vary according to the micro-ray voltage applied across the oscillating electrode. This can be explained as a result of a variation of the dielectric constant of the medium between the valve electrodes, the variation being caused by a corresponding variation of the density of electrons in the same medium.

When an incoming micro-ray wave of suitable frequency is impressed on antenna A_2, the high frequency potential along the oscillating electrode is varied and the apparent capacity shunting C_2 is also varied. These variations follow the change in amplitude of the incoming micro-ray wave. Therefore, the frequency which is produced in circuit $C_2L'_2$ undergoes a variation, and a frequency modulation of the intermediate frequency f is obtained, its amplitude remaining substantially constant for suitable adjustments of the voltages impressed on the micro-ray valve.

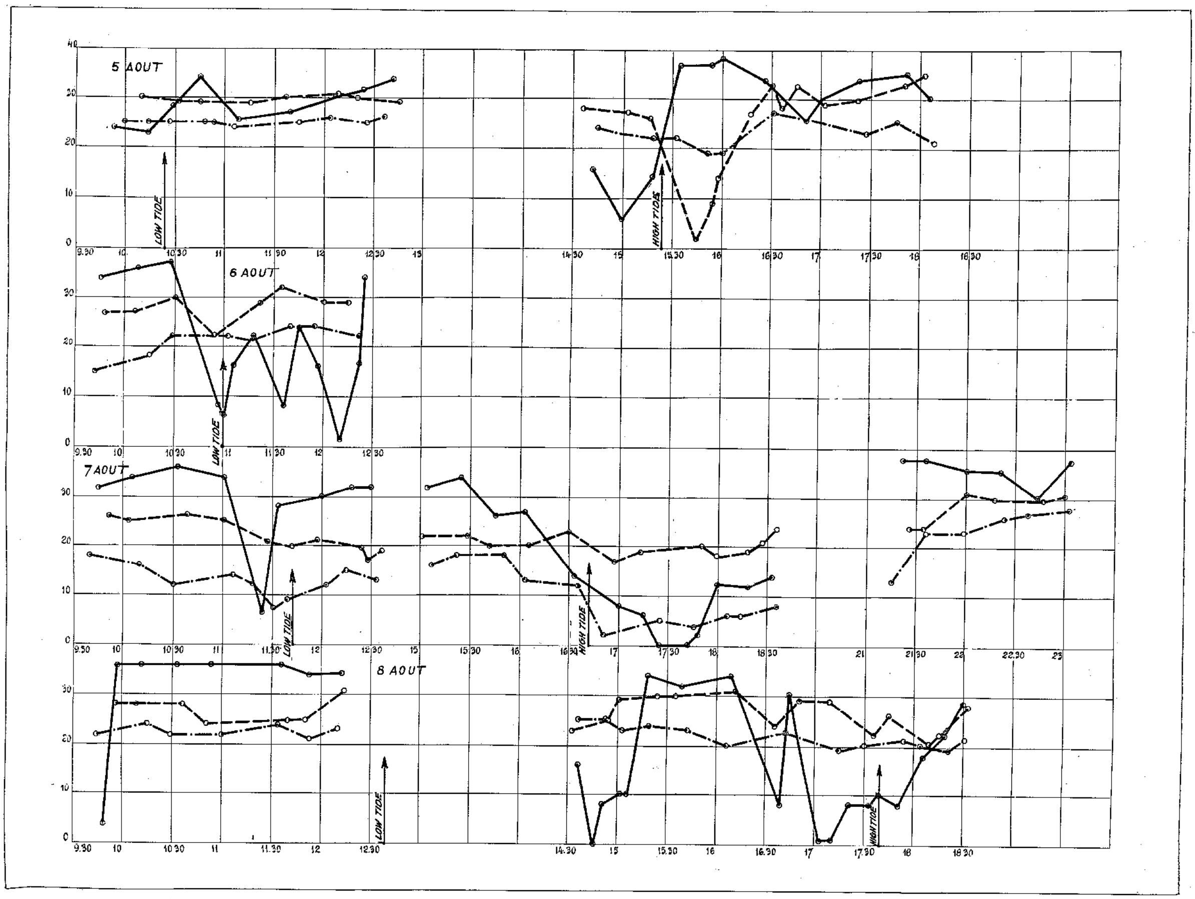

Fig. 10.

This local frequency modulated wave is subsequently transformed into an amplitude modulated wave by means of a resonant circuit and is then passed to the usual amplifying and detecting equipment. Additional low frequency amplification may be used, followed by a second detection, the signal then being applied to a standard volume indicator.

It is easy to adjust the 29 cm. receiving valve so that the intermediate frequency produced in circuit L_1C_1 is the same as that produced in circuit $C_2L'_2$ in the absence of any external micro-ray signal.

Comparison between signal levels and local noise levels can then be effected easily by means of the switch I. A series of long dashes was sent from the transmitters at frequent intervals, and measurements were based on the number of decibels of attenuation which it was necessary to take out of the measuring circuit in order to bring the noise level up to the same level as the signal. The results of the measurements are given on the accompanying charts (Figs. 6 to 10 inclusive). Though such results do not lead to any clear explanation of the propagation circumstances, they have definitely proved that these circumstances differ widely according to the wavelengths used, at least on the circuit under investigation.

The effect of the tide appears to be masked by irregularities in the flow of water in that part of the English Channel over which transmission took place. Certainly, results varied from day to day and transmission conditions appear to be different when the sea is smooth or rough.

Local interference in front of the receiving reflector is of very great importance. People walking along the cliffs caused very large sudden changes in the received signal strength. A similar effect occurred when ships were crossing the line of the beam at a certain distance. It can thus be inferred that an important part of the signal strength instability comes from the changes in the local interference pattern.

The effect of purely meteorological conditions could not be detected with reliability. As previously noticed, fading is apt to occur more frequently when the weather is hot, the humidity high, and the wind light. The signal strength on all three wavelengths was, as a rule, more stable in the morning than in the afternoon.

Reliable measurements have been taken for 117 hours during which the 18 cm. signal strength remained 18 db. above noise level for 99 hours; the 20 cm. signal strength remained 18 db. above noise level for 94 hours; and the 29 cm. signal strength remained 18 db. above noise level for 96.5 hours; that is, 84.6% of the time for 18 cm.; 80% of the time for 20 cm.; and 82.5% of the time for 29 cm.

If we now compute the percentage of time during which a combination of any two wavelengths would have produced signals remaining 18 db. above noise level, the following results are obtained:

18 cm. + 20 cm.—94% of the time;
18 cm. + 29 cm.—90% of the time;
20 cm. + 29 cm.—96.6% of the time.

These results, which apply to a period of time which was particularly unfavourable to micro-ray propagation, bear out the conclusion that the use of two wavelengths would definitely improve traffic reliability on the circuit under investigation.

Another interesting result from the tests was the development of a new method for receiving continuous wave micro-ray telegraphy.[7]

Referring again to Fig. 4 and considering, for instance, the 20 cm. receiving valve, the frequency f of the local oscillations in circuit $C_2L'_2$ can be adjusted in the absence of incoming signals to give a zero beat-note with a local stable auxiliary oscillator φ. As soon as a signal, a dash for instance, arrives on antenna A_2, the frequency of the local oscillation produced in $C_2L'_2$ is altered and becomes f_1, and the altered intermediate frequency f_1 and the local stable frequency φ produce a beat-note $\varphi - f_1$ in the detector equipment. If the amplitude of the signal impressed on A_2 varies within certain limits, the frequency of the beat-note obtained varies correspondingly, but not its amplitude, so that the system to a certain extent provides a means for the correction of fading.

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[7] Brevet Français 801.196.

Some Examples of Growth Curves*

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SUMMARY: *The present contribution first explains the application of growth curves in some special cases in the field of telephony and the importance of knowing the laws of growth in this field. Later it is shown how it is possible to adapt such curves to represent the increase in the number of subscribers within districts with different possibilities for development, and finally how the depreciation of composite plants may be influenced by growth curves of the kind treated here.*

Introduction

ONE of the first problems to present itself in engineering a telephone plant is the question of the incorporation of suitable reserve equipment.

In order to answer this question, it is necessary to make an estimate in each case of the increase to be expected in the number of subscribers or conversations in a period corresponding to the life of the plant under consideration, including not only the district but also connecting traffic centers. As every essential alteration in the increase thus estimated affects the profitableness of the plant, it is important to know the laws of the movements and growth involved.

Professor Axel F. Enström's article "Framstegslinien" (The Growth Curve) in the *Nordisk Tidsskrift for Teknisk Økonomi*, Nr. 1, 1935, prompted the author to take up some previously commenced investigations relating to increase in the number of subscribers and telephone density (i.e., number of subscribers per 100 inhabitants) within districts having different possibilities for development. A brief account of the results obtained may be of interest to readers of this journal.

Growth Curves

When estimating future growth, it seems natural to build on the knowledge of the development in the immediately preceding years, and it would appear that the estimated growth may be represented by the tangent to the progress curve. If this curve, however, has the appearance shown in Fig. 1 and the size of the plant is determined according to the tangent at A_1, including a reserve intended to meet requirements for the period (x_1 to x_1'), the plant would actually be filled up prematurely by (x_1' to x_1'') years. The opposite would be the case if the plant were designed according to the tangent at A_2; in this case the plant would cover the needs for (x_2'' to x_2') years longer than intended.

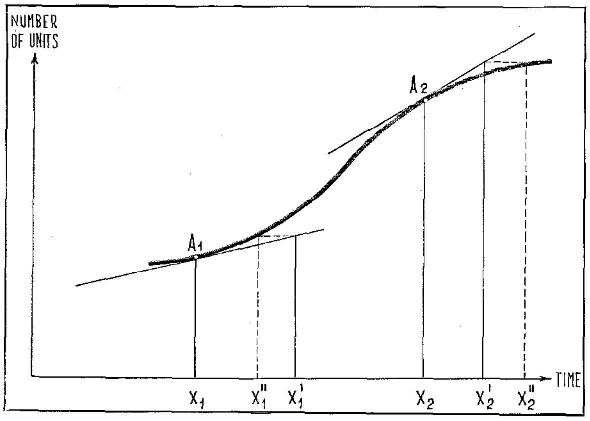

Fig. 1.

If the increase is considered not to progress linearly, it can be represented within limited periods by either:

$$y = ce^{bx} \tag{1}$$

$$y = a - ce^{-bx} \tag{2}$$

Curve (1), representing an infinitely increasing growth, assumes: firstly, an unlimited potential expansion in the number of units; and, secondly, a fixed ratio between the rate of increase $\frac{dy}{dx}$ and the number of units, y, currently required (see Table I). c, for example, may represent invested capital earning a return at compound interest, and b the "force of interest," where $b = \log_e(1+r)$ and r is the rate of interest per annum.

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* Translated and Reprinted from "Nordisk Tidsskrift for Teknisk Økonomi" (Nordic Journal of Technical Economy), Nr. 5, September, 1936.

Curve (2), on the contrary, assumes: firstly, limited potential expansion in the number of units, the curve becoming asymptotic to $y=a$; and, secondly, a fixed ratio between the rate of increase $\frac{dy}{dx}$ and the number of future units required (see Table I).

In a transition period—possibly as a connecting link between (1) and (2)—the increase may be represented by the above mentioned linear form of growth for which $\frac{dy}{dx}$ is constant.

As the growths investigated were all similar to that shown in Fig. 1, the three above mentioned curves could only be used to represent growth within limited periods; and it was therefore natural to attempt to find a single curve which could represent the whole course. As likely to fit the purpose, amongst others, two curves in the above mentioned article, and proposed by Pearl and Reed and Professor Axel F. Enström, respectively, were tried. Both have been employed to represent different courses of production.

In the expression for the first of the two proposed curves, a constant c was introduced for adjustment, thereby giving it the form in which it was tried:

$$y = \frac{a}{1+ce^{-bx}}. \qquad (3)^1$$

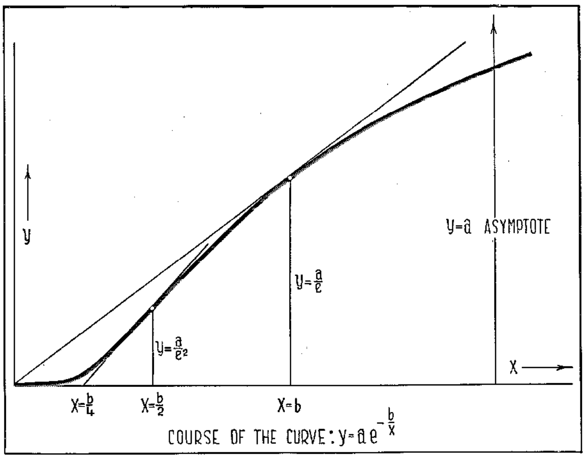

Fig. 2—Course of the Curve: $y = ae^{-\frac{b}{x}}$.

This curve, however, is symmetrical with respect to the inflexion-point. None of the growths investigated, however, displayed this characteristic; and, since it developed that the second curve,

$$y = ae^{-\frac{b}{x}}, \qquad (4)$$

fitted particularly well for the representation of the growths under investigation, this curve only was used.

The appearance and application of this curve to the representation of production is described in the previously mentioned article.[2] It shows, as will be evident from Fig. 2, some simple properties, particularly as regards coordinates and tangent; that is, the point of inflexion and the point at which the tangent passes through

TABLE I

$y=f(x)$	$\frac{dy}{dx}=f'(x)$	$\frac{d^2y}{dx^2}=f''(x)$	Some Characteristic Coordinates		
			for $x=0$ is	Inflexion Point	Asymptote
$y=ce^{bx}$	by	b^2y	$y=c$		
$y=a-ce^{-bx}$	$b(a-y)$	$b^2(y-a)$	$y=a-c$		$y=a$
$y=\frac{a}{1+ce^{-bx}}$	$\frac{b}{a}y(a-y)$	$\frac{b^2}{a^2}y(a-y)(a-2y)$	$y=\frac{a}{1+c}$	$x=\frac{\log_e c}{b}$; $y=\frac{a}{2}$	$y=a$
$y=ae^{-\frac{b}{x}}$	$\frac{by}{x^2}$	$y\frac{b(b-2x)}{x^4}$	$y=0$	$x=\frac{b}{2}$; $y=\frac{a}{e^2}$	$y=a$

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[1] This equation is also used to represent growth of population, see for instance "The Biology of Population Growth," by Raymond Pearl, New York, 1925.

[2] See further: "Om Kärnlinier i ekonomisk-statistiska kurvor," *Ymer*, by A. F. Enström, 1925, Nr. 3 and 4.

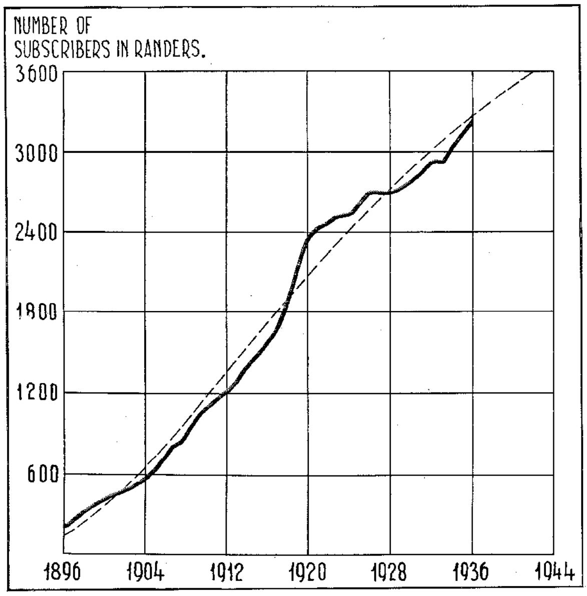

Fig. 3—Development of the Number of Subscribers in Randers
Number of Subscribers as of January 1, 1936...... 3,235
Number of Inhabitants as of January 1, 1936 approximately 39,200

the origin. This curve is thus easy to adjust.[3] The main data concerning it and the above mentioned curves are given in the table below:

Practical Application of the Curve $y = ae^{-\frac{b}{x}}$

Figs. 3 to 5 illustrate the application of this curve to the net increase in the number of subscribers in Jutish towns in the period 1896[4]–1936.

The computed curves are shown in dotted lines.

From the curves—see for instance the one representing the net increase in the number of subscribers in Randers—it will be seen how differing conditions in the two periods before and after the Great War gave rise to perceptible deviations from the computed curve. All the cases treated seemed to have the character of a "secular trend." By further attempts with similar representations of increase in the number of subscribers in other Jutish towns of different size, quite corresponding results were obtained.

In the cases investigated the starting point of the curve was fixed in the period 1882–1884, corresponding to the time when the increase in the number of telephones commenced in the towns concerned; and it was possible to place the inflexion point in the period 1912–1916.

For some few towns, and especially Aarhus (see Fig. 4), where the growth has had a linear character over a longer period and where, consequently, some uncertainty prevailed regarding the position of the inflexion point, it is possible that future development will prove that the inflexion point should be advanced somewhat.

A similar mathematical representation of the increase in telephone density within a certain district will be somewhat more complicated, because it will appear as the ratio between two curves with different conditions of growth (number of inhabitants and number of subscribers).

Conclusion

In addition to being used, as mentioned in the introduction, for determining the initial cost of the plant and for throwing light on the number of revenue yielding units within a particular district, growth curves of the kind treated here may also directly influence the calculation of the depreciation rate (per cent. per annum) for

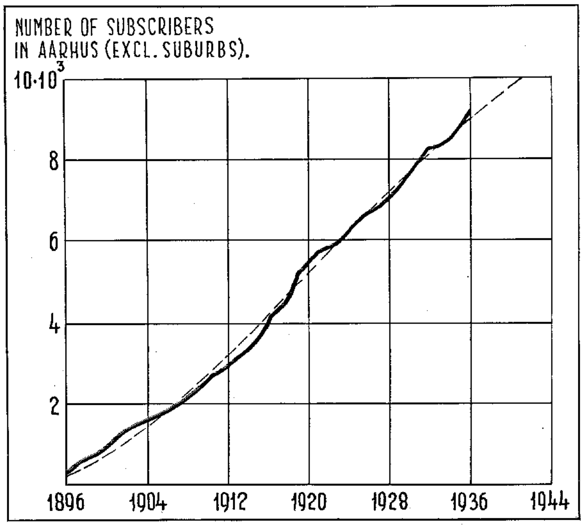

Fig. 4—Development of the Number of Subscribers in Aarhus (excluding Suburbs)
Number of Subscribers as of January 1, 1936...... 9,185
Number of Inhabitants as of January 1, 1936 approximately 90,500

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[3] Some mathematical properties of a similar curve $y=e^{\frac{1}{x}}$ are also described in "Cours d'Analyse," by Ch. Sturm, Paris, 1905, p. 313.

[4] The year when the Jydsk Telefon-Aktieselskab was founded by the fusion of a number of different minor companies.

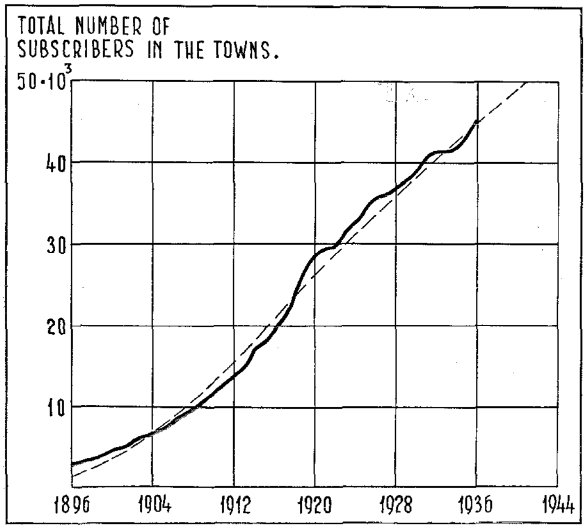

Fig. 5—Development of the Number of Subscribers in All Towns in the Territory Served by the Jutland Telephone Company

Number of Subscribers as of January 1, 1936..... 44,987

Number of Inhabitants as of January 1, 1936 approximately 517,500

composite plants constructed at different times but scrapped simultaneously.

The calculation of the depreciation of such composite plants is treated thoroughly by Professor P. O. Pedersen in an article, "Afskrivning paa tekniske Anlaeg" in "Polyteknisk Tidsskrift, Ingeniør og Samfund," Nr. 7–12, Copenhagen, 1929.[5]

Only a single typical example near at hand, therefore, will be briefly cited, i.e., pole lines with open wire.

If such a plant is built with a certain number of wires, which increase in proportion to the increase in the number of subscribers, a moment may arrive when it may, for different reasons, be considered advisable to take down a greater or lesser number of the wires and replace them with underground cables. The wires removed will then be of different age, and there will be among them some which, while not entirely depreciated, represent little or no value when taken down. Since the calculation of the rate of depreciation for the whole group of wires is based on its average life, the curve representing growth will influence the calculation of the average life that determines the depreciation rate in question.

Attention may finally be called to the following circumstances. The telephone density may differ widely in different quarters, especially in the larger cities where this difference can be very pronounced. In addition to knowing the growth curves of the kind herein treated, for the different quarters, it is therefore necessary further to know something of the character of the future developments relating to the building up of the town, and this not only for the suburban quarters, but also for the central portions, since centrally located quarters with small telephone density are frequently transformed into business sites with great telephone density.

For an engineer employed in the planning of extensions of telephone plant in a town of considerable size, the building plan of the town, if available, may therefore also provide a valuable aid.

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[5] This article has been reprinted in somewhat abbreviated form: "On the Depreciation of Public Utilities," by P. O. Pedersen, included in: "Miscellaneous Papers," Copenhagen, 1934.

X-Rays in Vacuum Tube Manufacture

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Standard Telephones and Cables, Limited, London, England

and

G. RABUTEAU
Les Laboratoires Le Matériel Téléphonique, Paris, France

ROENTGEN, in 1895, while experimenting with highly exhausted vacuum tubes, discovered that under certain conditions they emitted invisible rays with unique properties. Once a scientific curiosity, these rays—designated as X-rays because of uncertainty as to their nature—have become one of the most important tools available to modern industry.

The rays are produced when high speed electrons are stopped suddenly by collision with a metal anode. While for a long period the nature of the rays remained undecided, it was finally shown by Bragg that it was electromagnetic radiation of a wavelength considerably shorter than that of visible light. Von Laue and Bragg showed how it was possible to obtain diffraction effects by using a crystal as a diffracting grating. However, except in the special arrangements adopted to make use of this effect, as in X-ray crystal examination, the radiation can be considered as traveling in straight lines and not being subject to reflection or refraction.

The important characteristic for radiographic work is absorption, which varies with the material and which is a property of the atoms and not of the chemical compounds. The heavier the atoms, the greater is the absorption. The wavelength of the radiation produced by the X-ray tube decreases as the voltage applied to the tube increases, and at the same time it becomes more penetrating. Consequently, for the examination of objects of heavy materials, it is necessary to use high voltages.

The intensity of the radiation increases as the current through the tube increases. This does not affect the penetration of the rays but reduces the exposure required to obtain a negative of given density.

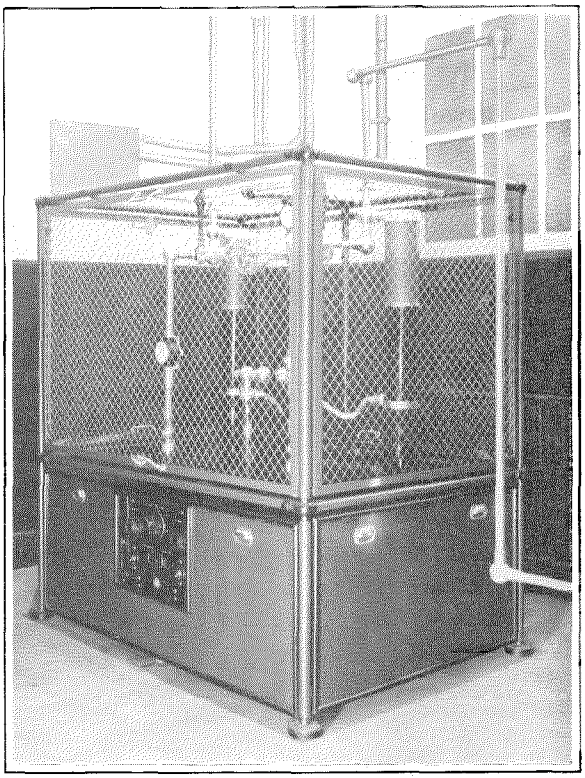

Fig. 1—High Tension Rectifier—Les Laboratoires Le Matériel Téléphonique, Paris.

In industrial radiography of vacuum tubes, the chief application is the photography of the interior of water cooled tubes through the anodes. These anodes may consist of 1.5 cm. total thickness of copper and the objects to be observed, i.e., the filament and grid structures, consist chiefly of molybdenum or tungsten which are to be seen by contrast on the negative. For this purpose, the most useful X-ray tube voltages are from 140,000 to 180,000 volts. The tube equipment, therefore, involves a high tension generator for providing these voltages and a tube current of the order of 3 or 4 milliamperes, as well as the electrical protective features necessary for safely handling the equipment.

The high tension generator may take one of a number of forms. For the high voltage work with which the authors are dealing, it is customary to supply the X-ray tube with unidirectional current so that some form of rectifier must be used. The X-ray tube itself acts as a rectifier but it is unsatisfactory for this purpose when working with high power, inasmuch as the target may operate at a temperature sufficiently high to emit electrons. In this event, breakdown would occur when the tube ceases to act as a rectifier. Mechanical rectifiers are used to some extent but are, of course, very cumbersome and noisy; both the installations to be described below operate with valve rectifiers.

The X-ray tube itself consists of a highly evacuated glass bulb provided at one end with a stem carrying a filament and, at the other, a stem carrying the target or anticathode, which is located close to the filament. The filament is a coiled tungsten wire heated by a current to a temperature such as to provide a total emission of the required value. The anticathode is a button of tungsten mounted on a water cooled copper rod or on a massive tungsten rod. The face of the anticathode is at an angle to the direction of arrival of the electrons. The high voltage is applied to the tube with the positive pole connected to the anticathode, the electron current from the filament causing intense bombardment and producing the X-radiation. Since the anticathode operates at an extremely high temperature, the recommended maximum ratings for the tube must be strictly adhered to or it may be permanently damaged.

When X-rays strike any object, part of the energy is scattered in all directions from it with a longer wavelength. This is called secondary

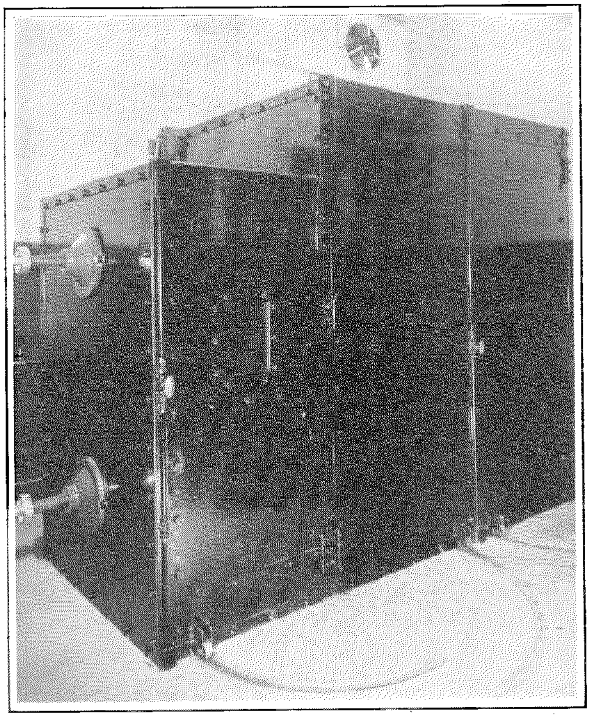

Fig. 2—X-Ray Chamber, Paris Laboratories.

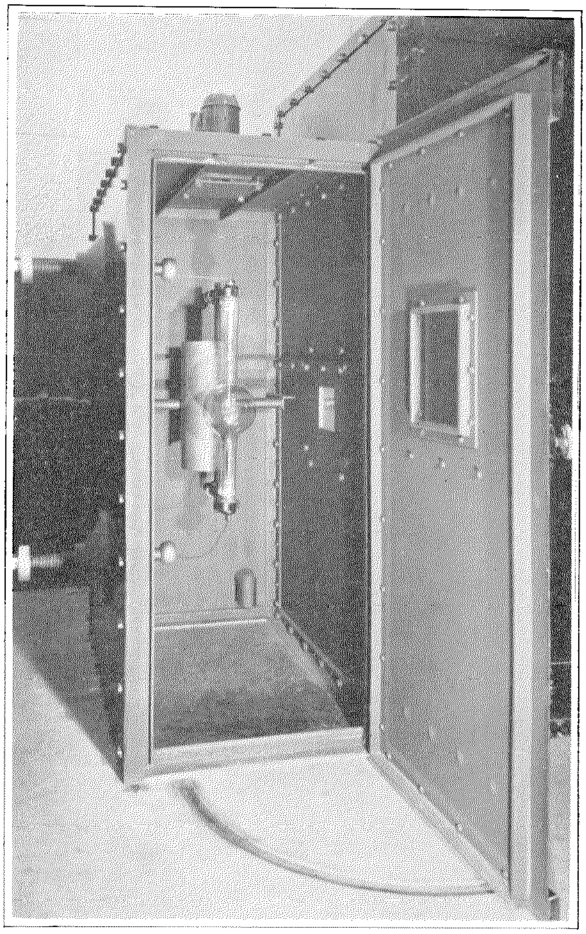

Fig. 3—X-Ray Tube Compartment, Paris Laboratories.

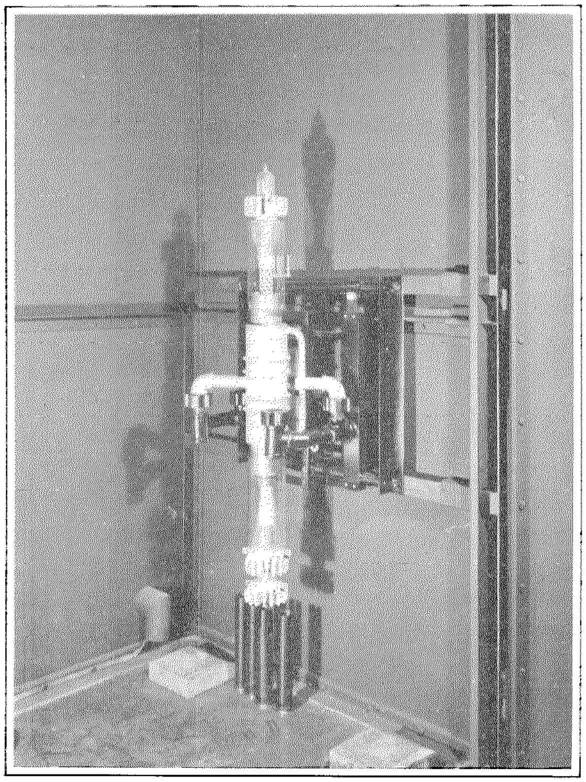

Fig. 4—Interior of Right-Hand Compartment of X-Ray Chamber with Vacuum Tube in Position.

radiation and it in turn, falling on other objects, will be scattered again.

This radiation is, therefore, very difficult to control, and the only way of stopping it is by the use of an appropriate thickness of lead sheet, say 3 millimeters. It must, however, be properly controlled for the safety of the operator since the effect of small doses is cumulative and can lead eventually to anaemia and general debility. It is, therefore, necessary to take suitable protective measures and also to provide for periodical medical examination of the operators who might be exposed to the radiation. The examination, apart from a general one, usually involves a count of the red corpuscle concentration of the blood.

The problem of protection of staff can be solved in two ways, and the installations in the Paris Laboratories and in the Valve Department of Standard Telephones and Cables at Woolwich represent the different methods.

In the Paris installation, a rectifier unit consisting of a high voltage transformer and suitable high vacuum rectifiers is installed in a room which is completely separated by grounded screens from the operating section. The high voltage is fed into the X-ray tube chamber in which an air cooled tube is mounted. This whole chamber is built of lead with tightly fitting doors, and is provided with a window having a lead shutter for the admission of the radiation to the camera box, which is a very large lead box with heavy lead doors and which contains the support for the object to be radiographed and the film. The X-ray tube and the object being examined are thus completely en-

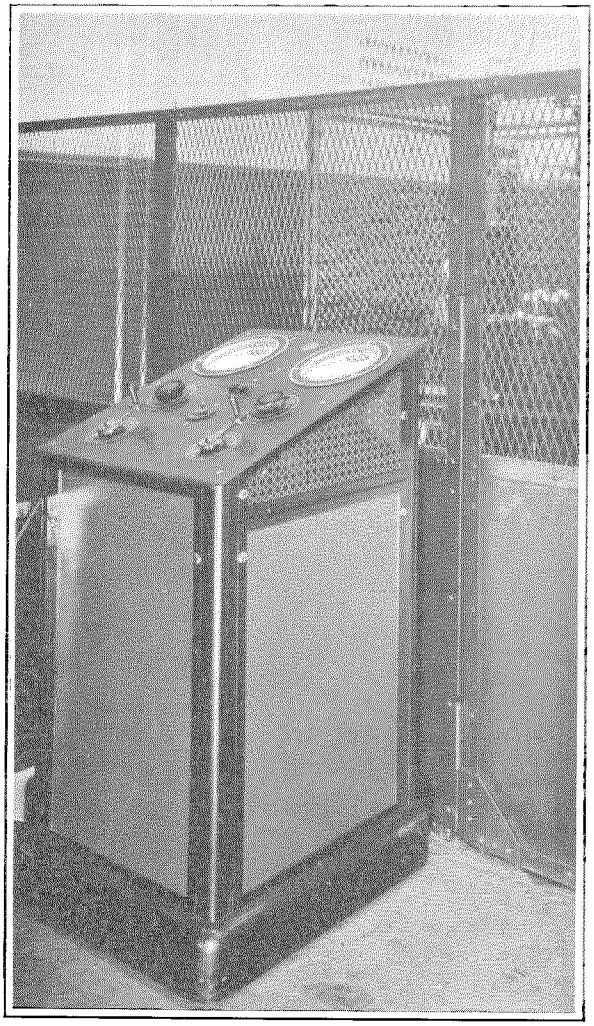

Fig. 5—Control Desk, Paris Laboratories.

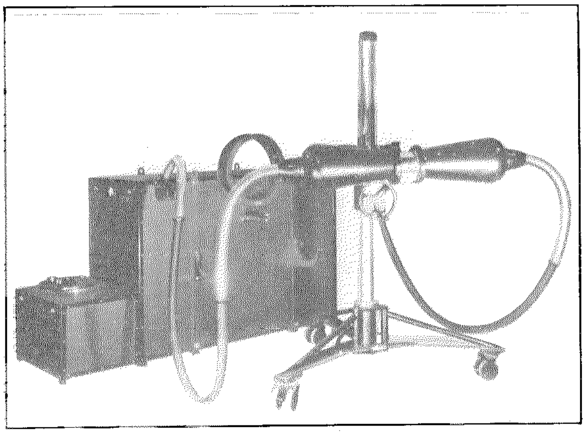

Fig. 6—Complete X-Ray Unit, Valve Department, Standard Telephones and Cables, Limited, Woolwich.

closed in lead and the operator is quite protected from radiation.

Fig. 1 shows the high tension rectifier which comprises a high voltage transformer having its mid-point earthed, two half-wave high tension tungsten filament rectifiers, two high tension condensers and the necessary filament transformers, voltmeter and control for the adjustment of the filament voltage of the rectifier tubes, and the X-ray tube.

The unit is fully protected by appropriate earthed screens. The positive and negative terminals of this rectifier, which is rated to deliver continuously 200,000 volts and 10 milliamperes d-c., are connected to aluminium bus bars of a diameter large enough to avoid Corona effect.

Fig. 2 shows the X-ray chamber which is an iron frame covered with 5 mm. lead and provided with doors giving access to two different compartments. The compartment on the left contains the X-ray tube; the other, the vacuum tube to be examined.

Fig. 3 shows the X-ray tube compartment, the door being open. The X-ray tube, which is of the air cooled type, is mounted on appropriate insulators. The high tension is fed to the cathode and anode of the tube through bushings fixed on the panel at the left of the chamber and made with an insulating material containing a considerable amount of lead oxide in order to prevent X-ray radiations from passing through them.

A fan is arranged on the top of the X-ray tube chamber for removing the ozone produced in the chamber by the high voltage field around the conductors.

A glass window on the front door enables the operator to supervise the operation of the X-ray tube. The glass used for this window contains about 20% of lead and its thickness is great enough to provide the same protection as that of the other parts of the chamber.

Fig. 4 shows a view of the interior of the right-hand compartment of the chamber with a vacuum tube in position for examination.

The tubes can be placed in position in a few seconds by means of appropriate supports. Each tube to be examined is photographed in two directions at suitable angles depending on its inner construction. The tube supports are arranged so as to determine with accuracy the position of the tube for each of the two photographs taken. From the latter, the location of any part inside the tube can be accurately determined.

Provision has been made to render possible, when required, the application of filament voltage

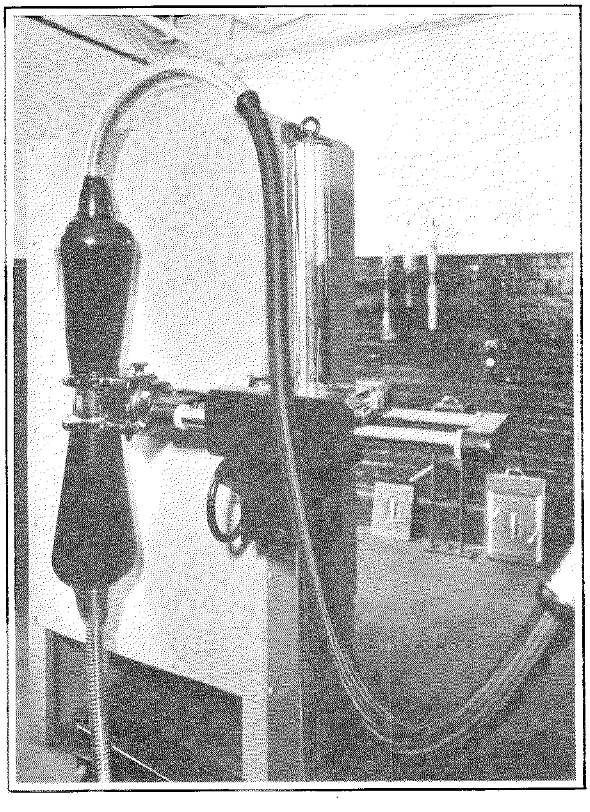

Fig. 7—X-Ray Tube and Camera, Woolwich.

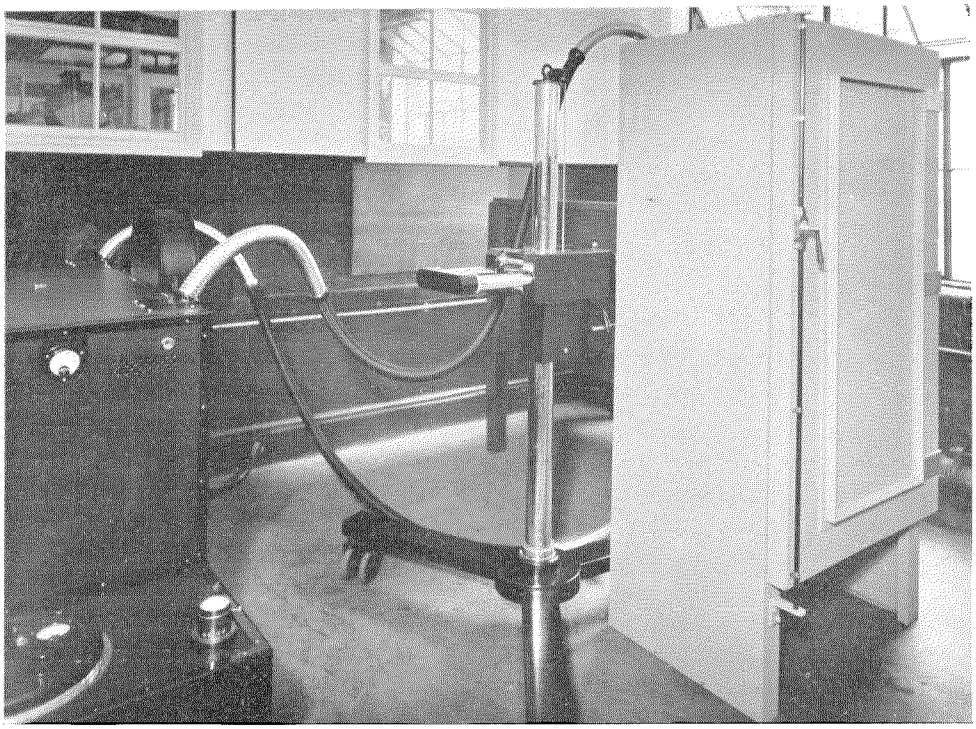

Fig. 8—Installation for Routine Examination of Water Cooled Tubes, Woolwich.

to the tube during examination, so that deformation of the filament when hot or during the heating and cooling cycle can be recorded.

The film is contained in a suitable chassis having an aluminium window which is held in position by means of appropriate rails, one of which can be seen on the right of the tube in Fig. 4.

Fig. 5 shows a view of the control desk which comprises devices for the remote control of the output voltage and current together with the necessary meters. A push button controls the contactor applying the high voltage. In order to protect the operators, contacts mounted on the door remove the power as soon as a door is opened.

The equipment installed in the Valve Department of Standard Telephones and Cables, on the other hand, consists of what is called a self-protected X-ray unit. Fig. 6 shows the complete unit. The large steel box contains all transformers, rectifiers, insulated water circulating pump and water cooling radiator together with control gear. The tube is shown mounted on its stand and in its housing. The X-ray tube has a water cooled target and is connected to the high voltage generator unit by flexible cables. One of these contains, in addition to the negative lead of the H.T., wires for the filament supply. The other contains the positive lead of the H.T., and inlet and outlet hoses for the water cooling, the water being circulated by the insulated pump and passing through the radiator in the transformer box. The flexible cables are metal sheathed and earthed. The X-ray tube itself is completely surrounded by a metal earthed shield. The whole unit is thus completely electrically protected. The mid-point of the high tension circuit is earthed and thus the cables have to support 90 kilovolts each.

The X-ray tube shield is also a very efficient radiation screen and the intensity escaping, except via the window, is reduced to a safe level.

The X-ray tube used in this equipment is of special type, which has a grid between the filament and anode. A negative voltage is applied to this grid in such a way that the anode current only flows at the time when the anode voltage is close to its peak value. As a result, the heating of the anode only takes place at the moment when the most useful rays are being produced, thus increasing the effective rating of the tube, and at the same time there is a very considerable reduction in radiation of the unwanted softer rays.

The tube is mounted on a universal stand, and its position can be adjusted rapidly for any special use. For the general work of photographing water cooled tubes, the window of the tube is placed in contact with the window of a large lead cabinet which is fitted with special tube holders and film carriers so that the time required to set up for a picture is reduced to a few seconds. The whole apparatus is controlled by a single push button plus a voltage selector. The tube in position against the camera is shown in Fig. 7.

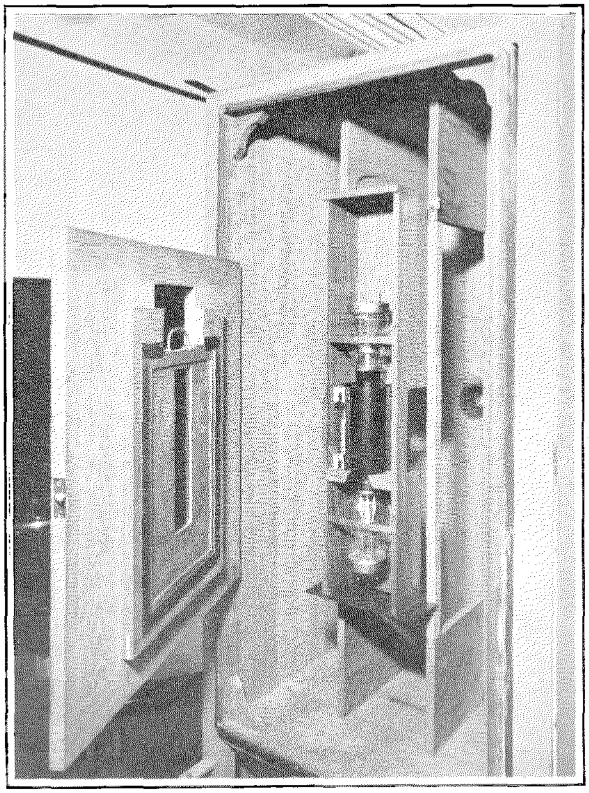

Fig. 9—Interior of Camera showing a Vacuum Tube in Position for Examination, Woolwich.

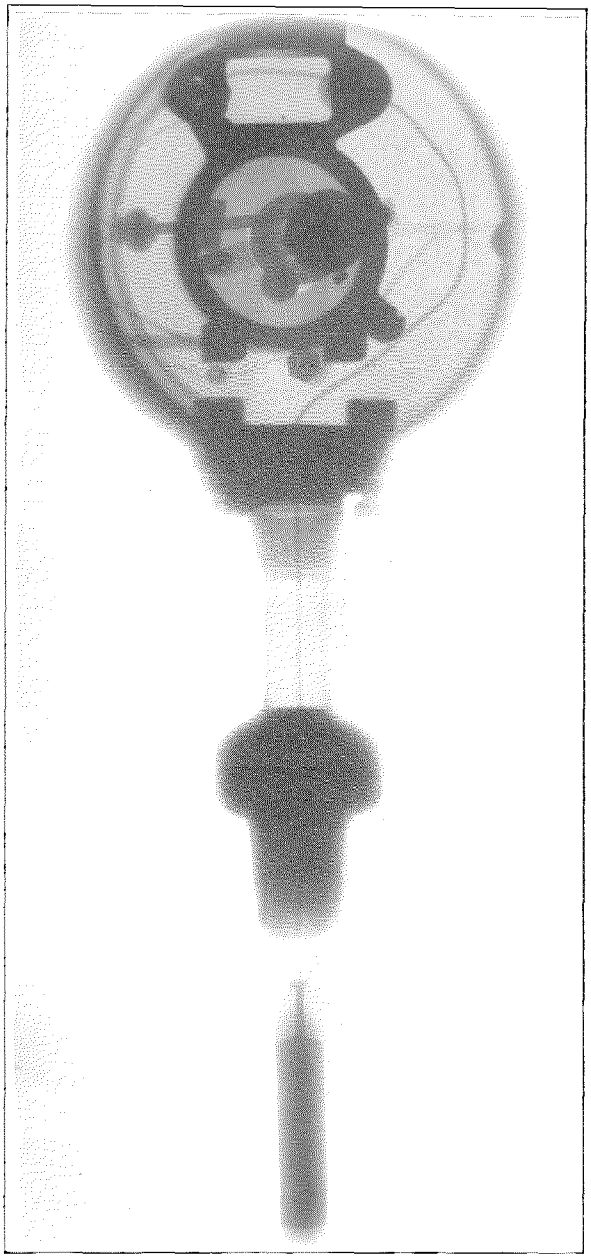

Fig. 10—Radiograph taken with Lead Table Set-Up.

This equipment, being flexible, can fairly easily be set up for any special and unusual job or even be moved bodily to another part of the factory

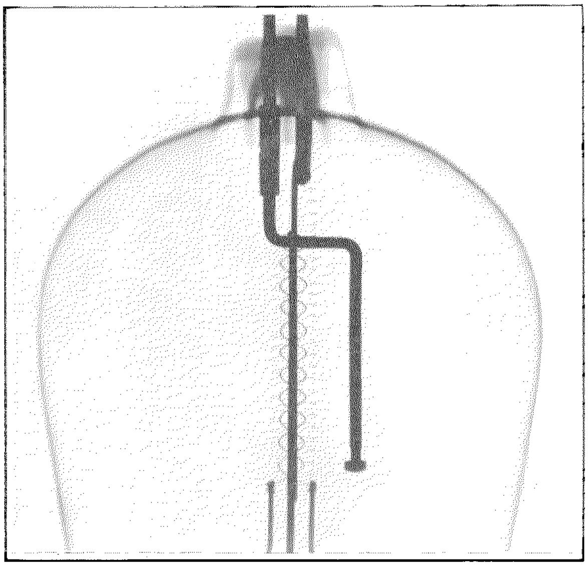

Fig. 11—Radiograph of the 4304-A Vacuum Tube. This Tube has a Carbon Anode, which is Invisible in the Reproduction.

for the examination of equipment that cannot be moved. Recent jobs have included the examination of the welds of parts of machinery in pieces 14 feet long.

Two self-starting electric clocks are provided, one of which measures the filament burning time of the X-ray tube, and the other the total time of application of the high voltage.

Fig. 8 shows the installation at the Woolwich factory for the routine examination of water cooled tubes. The cabinet on the right is the camera, made of thick lead.

Fig. 9 is a view of the interior of the camera and shows a vacuum tube in position for examination. Tubes can be placed in position in a few seconds with very exact positioning. The hinged door on the left carries intensifying screens, if used, and the film holder.

The actual process of taking the radiograph is sometimes carried out with, but more usually without, intensifying screens. In either case, a thin steel screen is placed between the vacuum tubes and the film to improve the contact. The exposures are short and rarely exceed one minute.

While the majority of the work handled is of a routine nature capable of being quickly dealt with by this apparatus, it often happens that it is necessary to examine other articles. For this purpose a heavy lead table has been built. The lead is wood covered but gives very considerable protection to the operator. The tube in this case is used in a horizontal position. Fig. 10 is a radiograph of a piece of apparatus for which this set-up was employed.

The normal routine in Standard Telephones and Cables requires that every water cooled tube be photographed during its manufacture in two directions at right-angles. New types of tubes are often photographed a greater number of

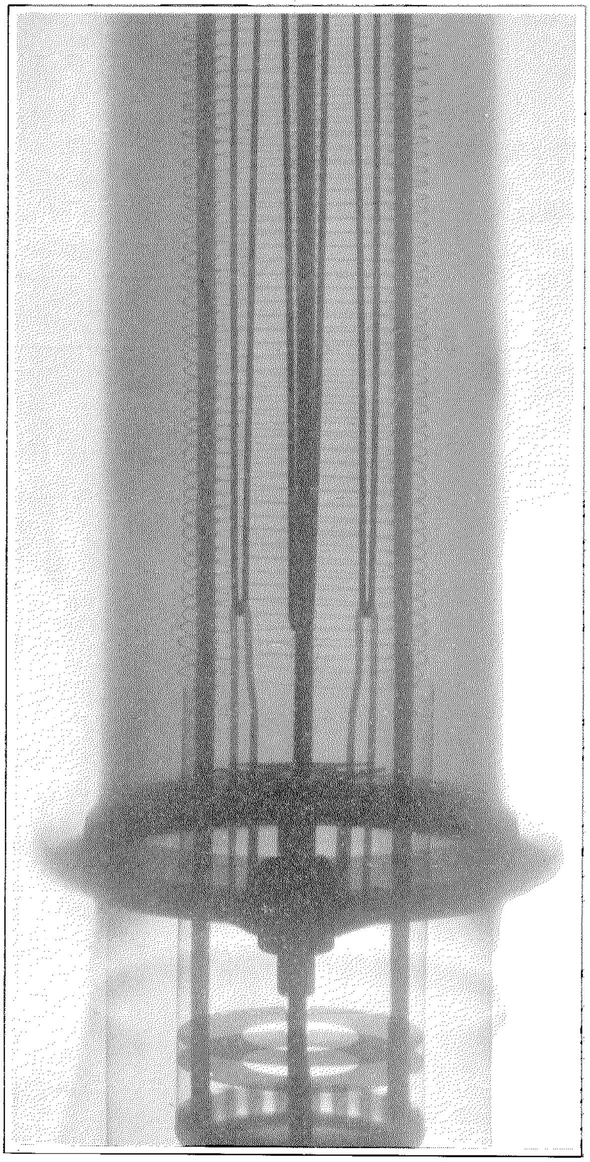

Fig. 12—Radiograph of Part of a 4030-B Vacuum Tube.

times until all manufacturing troubles have been eliminated.

The process has been found of very great value in improving the quality of the tubes, and the defects which are completely eliminated, for nstance, are such as:

Inaccurate centering or alignment of electrodes,
Distortion of electrodes during exhaust,
Thin spots in anodes,
Burnt out, distorted, or loose turns on grids,
Filament anchor connectors not screwed completely home.

Figs. 11, 12, and 13 illustrate typical radiographs.

The use of this equipment has undoubtedly prevented the shipment of apparently perfect tubes which contained hidden defects. The rejection of work as a result of examination of the radiographs also has had a certain moral effect on the operatives, resulting in a very marked improvement in the standard of the work.

While the main function of the apparatus is the radiography of water cooled tubes, it is frequently found to be of value to photograph glass tubes, especially of the multi-electrode type, to determine the reasons for defects. Previously, when such tubes were cut open for examination, the process of dissection itself disturbed the very errors of assembly, etc., for which search was being made. In such cases, two photographs are often taken, the X-ray tube being slightly displaced between the exposures. The negatives are then examined in a stereoscope to give a good idea of the spatial arrangement of the electrodes.

The X-ray apparatus has proved itself an indispensable tool in vacuum tube manufacture and its value is such that its application will gradually be extended to wider fields in the manufacture of communication apparatus.

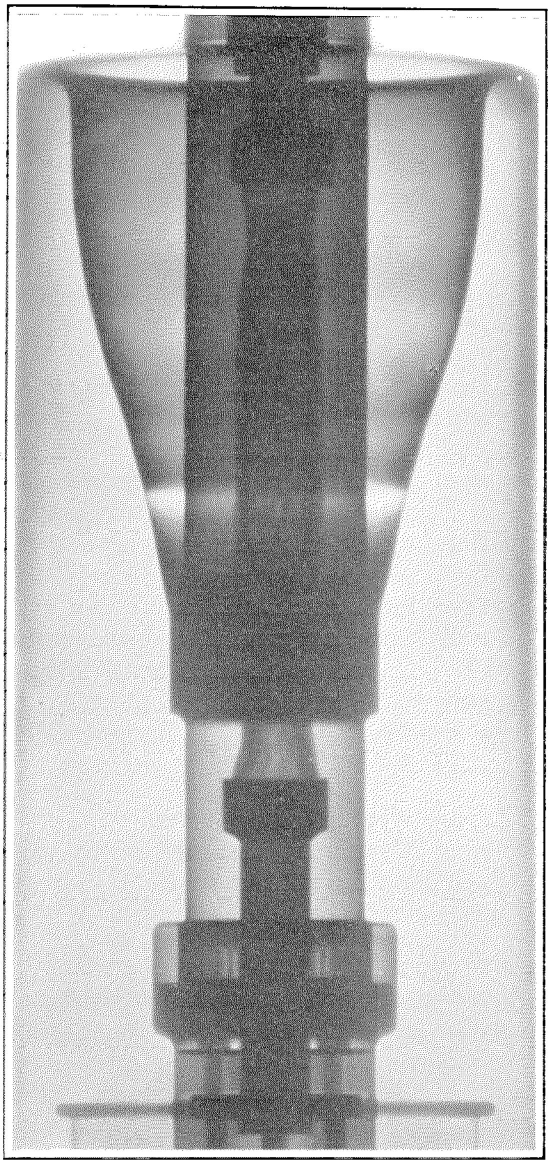

Fig. 13—Radiograph of the Filament Stem of a 4030-B Vacuum Tube, showing Concentric Filament Leads and the Flexible Nature of the Inner Lead.

An Experimental Television Transmitter

By S. VAN MIERLO AND P. GLOESS
Les Laboratoires Le Matériel Téléphonique, Paris, France

General

AFTER preliminary work on television pick-up equipments, a complete system for ultra-short wave transmission and reception of film pictures was prepared in 1935 by Les Laboratoires Le Matériel Téléphonique, Paris. A series of tests was made between Avenue de Breteuil and Champs-Elysées and the results were comparable to those obtained elsewhere in Europe at the time. The television transmitter used an arc lamp and a scanning disc.

In view of further studies in connection with television problems, and particularly the development of terminal equipment and amplifiers for transmitting television signals through cables, it was decided to build a new laboratory film scanner having the following characteristics:

(1) Easy operation and maintenance,
(2) Number of scanning lines to be easily adjustable from 180 to more than 400 lines.

In order to satisfy the first requirement, the use of an arc lamp as light source was excluded. With such a lamp, it is very difficult to obtain a steady illumination and the time required for maintaining the equipment in proper adjustment, etc., is relatively great.

The second requirement eliminated the use of a scanning disc which would involve changing the disc when passing from one number of lines to another.

The simplest and probably the most satisfactory solution was to give a continuously vertical movement to the film and to scan it horizontally by means of the image of the spot produced on the screen of a cathode ray tube. The more complicated tubes used lately for television pick-up are not so interesting for film scanners.

The light, modulated by the film, is directed into a photoelectric cell.

The complete scanner, with most of the covers removed from the panels, is illustrated in Fig. 1. A short description of the different parts is given below. Fig. 2 shows the general circuit arrangement.

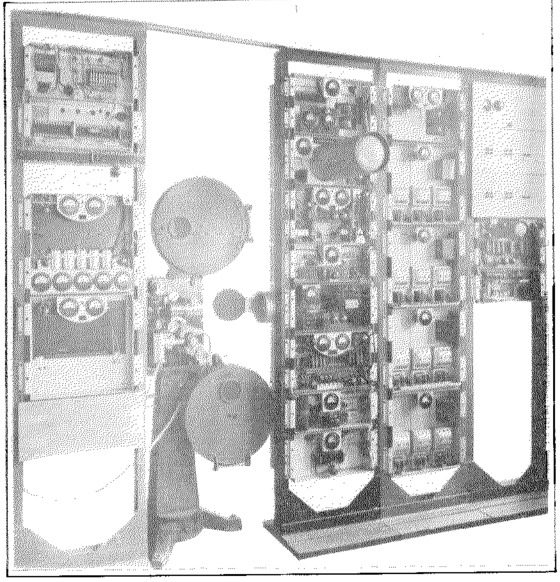

Fig. 1—Complete Scanner.

Frequency Generator

For a given number of scanning lines, it is necessary to have available a corresponding frequency for the production of synchronisation signals which control the movement of the spots, both of the scanning cathode ray tube and of the distant receiving tubes.

These frequencies must be multiples of the main current frequency so that any pattern visible on the receivers, as a result of incomplete filtering, has a fixed position on the screen. In case of non-synchronisation, a "hum" pattern would travel slowly across the image and cause a very disagreeable visual impression.

A group of panels is provided for obtaining multiples of the fundamental frequency, the following frequencies having been considered more especially: 4,500, 5,625, 6.000, and 10,125 cycles per second. A large number of other frequencies can be obtained if required.

Synchronisation Signal Generator

The sinusoidal currents of the generators are transformed by a series of circuits into a succession of very short impulses. These are used to control the relaxation oscillator of the scanning cathode ray tube and are also sent to a mixing panel described below. The methods used are such that extreme stability is obtained. A cathode ray tube is provided to check the shape of the synchronising signals and, in general, to control the operation of the above equipment.

Scanning Cathode Ray Tube

This is a very special cathode ray tube, fulfilling the following conditions:

(1) Very brilliant and small spot,
(2) Afterglow of less than 1 microsecond,
(3) Uniform screen,
(4) Reasonable life.

It is well known that all screen materials do not only produce light during the time they are bombarded by electrons, but remain luminescent some time after. The first effect is usually fluorescence, the second phosphorescence. This afterglow should be of very short duration in the present case; for, otherwise, the horizontal definition would be insufficient, several picture elements being illuminated simultaneously. It is difficult to reduce this time to less than 1 microsecond but, fortunately, it is possible to improve conditions by making use of the fact that the wavelength of maximum amplitude of the afterglow (some 6,000 Angström) is different from that of the first glow (some 5,400 Angström). It is therefore possible to eliminate to some extent the effect of the afterglow by using a filter or else a photo-cell which is much less sensitive to the afterglow.

There is no doubt that cathode ray tube technique can be greatly improved and that, in the future, very satisfactory tubes even for the highest definitions will become available.

In order to produce sufficient light, anode tension must be rather high: 6,000 volts have been used thus far in these Laboratories. Decreased illumination, which tends to increase the life of the tube, apparently results partially from decreased cathode emission and partially from the aging of the screen. Decrease in cathode emission can be avoided practically. To increase screen life the spot is not moved along a single horizontal line, but scans a surface of adjustable height, thus also avoiding a light saturation effect in the screen. A small portion of the pictures or of the intervals between pictures is lost by this method but this is inconsequential in practice.

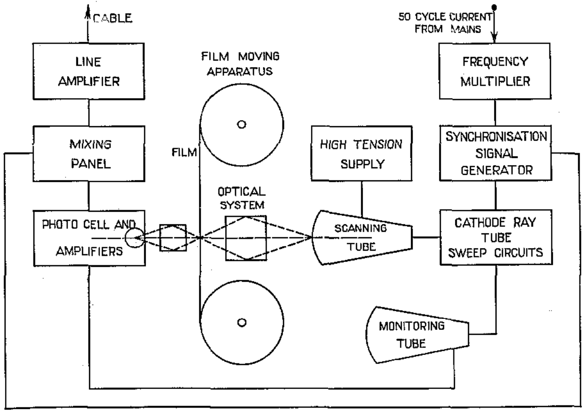

Fig. 2—General Circuit Arrangement of Scanner.

The circuits are arranged also for scanning the film when at rest.

The sweep circuits are carefully designed to produce a very uniform scanning.

A monitoring cathode ray tube, operated with the same circuit as the scanning tube, is arranged to receive the picture signals and so to reproduce the picture. The effect of any adjustment, therefore, can be controlled immediately by the operator.

Film Moving Apparatus and Optical Systems

A special and compact unit has been developed for moving the film vertically in a very uniform way. A sound head is provided and a high grade optical system is used to project the scanning spot on the film with little loss of light and definition.

Photo-cell and Amplifiers

The amount of light passing the transparent parts of the film is extremely small (for instance, less than 10^{-3} lumen for a definition corresponding to 240 lines) and an amplification of more than 100 db. is needed to obtain normal signals. Electron multipliers of special design can solve the problem but, since they were not available in time, it was necessary to develop an amplifier using vacuum tubes.

As previously mentioned, the photo-cell must have a special sensitivity curve adapted to the spectrum of the scanning ray tube. Unfortunately, cells having the required maximum of sensitivity are not very efficient, as a current of only about 10 microamperes is obtained per lumen. Doubtless, improvement can also be expected in this direction.

One of the difficulties in the design of the amplifier is the wide frequency band, commencing at some 10 cycles per second and extending to some 2 megacycles per second. It is sometimes considered easier not to amplify this band as it is, but to use a carrier modulated by the signals. To take full advantage of this method, it would be necessary to use a rather high frequency for the carrier and it then becomes very difficult to handle the signals. The modulation process, furthermore, must be applied carefully to avoid intermodulation. The modulation method, therefore, presents serious difficulties and it was decided to use, tentatively at least, a straight amplification of the normal frequency band.

The main problem in the amplifier, however, is that of noise. In addition to noise due to mechanical vibration and to interference from outside, it is well known that, with small input levels, the noise due to thermal agitation in the resistances and to various causes in the tubes becomes comparatively important. Tubes must therefore be chosen carefully or be made specially to reduce shot and flicker noise and to avoid ionisation and secondary emission.[1]

The noise due to thermal agitation can be cut down by choosing certain circuit conditions. The following calculation gives in a simple way a guide for the choice of the circuit elements.

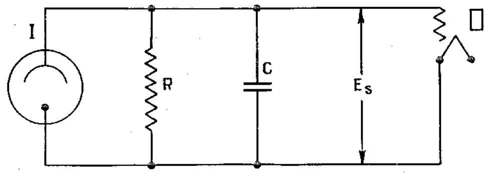

Fig. 3—Simplified Circuit showing Coupling between a Photo Cell and a Vacuum Tube.

The simplified circuit of Fig. 3 shows the coupling between a photo-cell and a vacuum tube. I is the current in the photo-cell, R the combined resistance of a resistor and the insulation of the photo-cell and tube, C the combined capacity of the photo-cell, the resistor, the tube, and the wiring. The value of the signal potential difference E_s at the input of the tube is $I \times Z$ when Z is the impedance of R and C in parallel. We have, therefore:

$$E_s = \frac{IR}{\sqrt{1+\omega^2R^2C^2}} \cdot$$

The potential difference of the thermal agitation noise at the input of the tube for a frequency band equal to 1 is

$$E_T = 2\sqrt{kTr}$$

as shown in an article in the *Physical Review*,[2] where k is the Boltzmann constant, T the absolute temperature, and r the resistive component of the combination of R and C in parallel. It is very important to note that it is not R, but r which is to be used in this formula.

We find finally that the ratio signal to noise is equal to

$$\frac{E_s}{E_T} = \frac{I}{2}\sqrt{\frac{R}{kT}} \cdot$$

Since k cannot be controlled, changes in T are of little help. It will therefore be seen that besides increasing I as much as possible, the resistance R should also be increased. The high frequencies will then be attenuated much more than the low frequencies, but a correction can be made later.

The upper limit of this resistance is determined partially by the fact that it is not advisable to reach values corresponding to the insulation resistances and the leakage resistance corresponding to the grid current of the tube unless these are maintained very stable, and partially by the consideration that there is no reason to increase the resistance further when the thermal agitation noise becomes of the same order as the tube noises.

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[1] "Fluctuation Noise in Vacuum Tubes," by G. L. Pearson, *Bell System Technical Journal*, October, 1934.

[2] "Thermal Agitation of Electric Charge in Conductors," by H. Nyquist, *Physical Review*, July, 1928.

These considerations led to the use of a photocell resistor of unusually high resistance (50 megohms).

The unavoidable thermal noise in the plate circuit can be reduced by employing small plate tensions and large outside resistances. Elimination of noise due to extraneous causes requires mechanical and electrical filtering.

Fig. 4 shows the circuit of one of the amplifiers used during the development period. Without special precautions, the use of a very high input resistance would cause overloading of tubes at low frequencies. In the present case, the amplitude distortion due to this input circuit is corrected partially by the plate circuit of the first tube. L_a and R_a are chosen in such a way that the signal-to-noise ratio is not decreased appreciably. A resistance R_c is placed in the cathode circuit of the first tube, which is a high frequency pentode and which, by negative feedback, decreases somewhat the noise due to its anode current. The voltage drop in this resistance is also used to obtain the required potential at the control grid.

As the impedance of the anode circuit is very small at the low frequencies, the anode battery and filtering circuit is not included in the coupling circuit. The battery is used also to polarise the photo-cell.

The only special feature of the second stage is the very high resistance value of the anode resistor. The third stage provides a further correction of the amplitude distortion, and is very similar to the first. The fourth stage is arranged to adapt the amplifier to a short coaxial cable leading to a second amplifier.

Mixing Panel and Line Amplifier

The amplified television signals and the synchronisation signals can be mixed together in various proportions as required.

As signals will usually be transmitted over a certain length of cable having an impedance of the order of 70 ohms, a line amplifier is provided in order to obtain a sufficient voltage at this low impedance.

Switching and Safety Arrangements

By means of switches it is possible to change from one type of scanning to another.

Relays are provided in order to avoid the high tension being applied on some circuits before cathodes have heated up sufficiently. It is, therefore, possible to start the transmitter by simply pressing a button.

These arrangements also aid in making the operation easy and in reducing maintenance. It has been found that one operator is amply sufficient to take care of everything, including the handling of the films, while two men are needed to give satisfactory service with an apparatus using arc lamp and scanning disc.

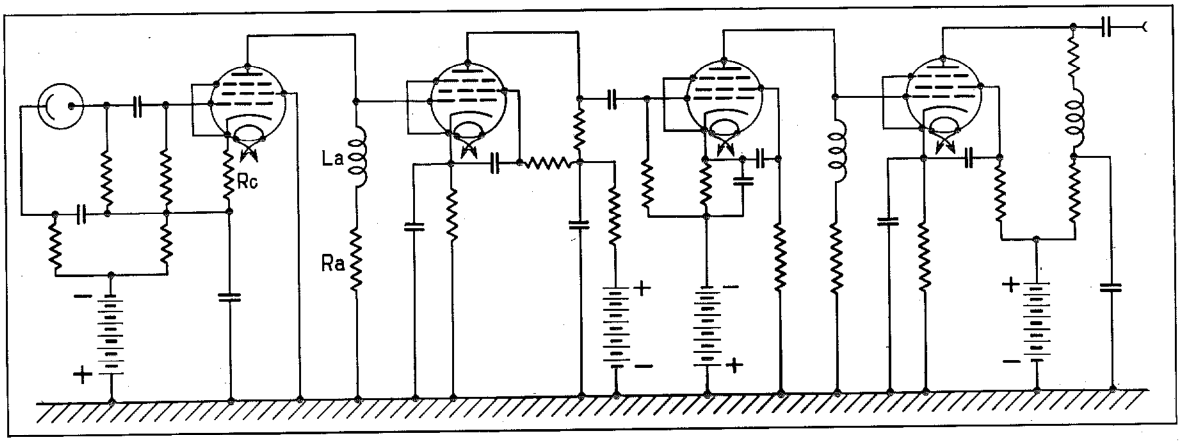

Fig. 4—Circuit of an Amplifier used during Development Period.

An Experimental Television Receiver

By S. VAN MIERLO and C. A. PULLES
Les Laboratoires Le Matériel Téléphonique, Paris, France

General

THE first models of television receivers developed for testing purposes during 1935 yielded information for the construction of a new receiver. The plan was to arrange it for the reception of 180 line pictures transmitted from the Eiffel Tower and also for 240 and 405 line pictures transmitted by Les Laboratoires Le Matériel Téléphonique equipment.

Fig. 1 shows a rear view of the television receiver. The equipment comprises three units: one unit is an ordinary audio receiver; the second is a broad band short wave visual receiver; and the third includes the deflecting circuit which moves the spot on the screen of the cathode ray tube and the power supply for the cathode ray tube.

A separate audio receiver is provided for the reason that audio signals are transmitted from the Eiffel Tower on a wavelength of 206.0 or 431.7 meters, while television signals are sent out on an ultra-short wave transmitter.

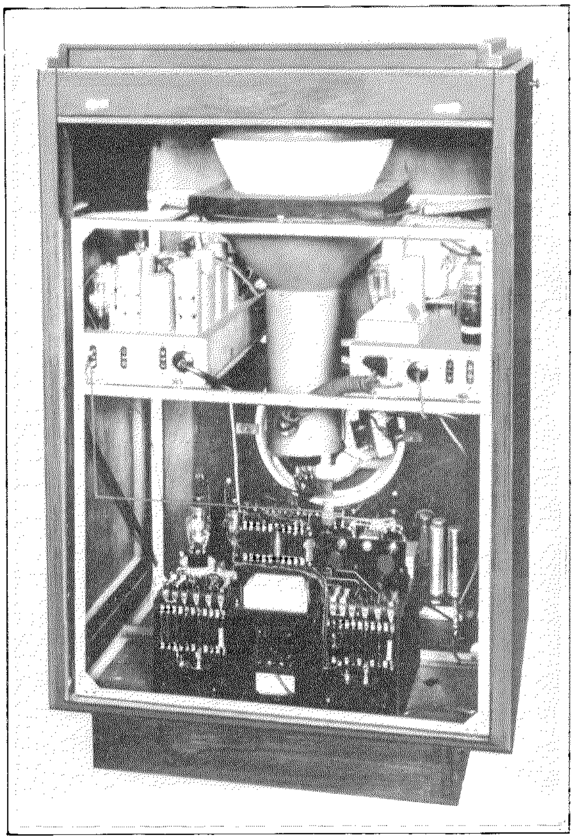

Fig. 1—Television Receiver—Rear View.

Visual Receiver

The broad band visual receiver operating on 6 to 10 meter wavelengths is a superheterodyne receiver with three intermediate frequency stages, a diode-triode detector-amplifier, and one "low" frequency amplifier stage, at the output of which the modulating grid of the cathode ray tube is connected, as well as a circuit for separating the television signals from the synchronisation signals.

As at present developed, a frequency band of more than 1 megacycle per second can be passed.

Separating Circuit

Fig. 2 shows how the modulating grid of the cathode ray tube and the separating circuit are connected to the plate circuit of the low frequency amplifier stage.

The grid of the separating tube has a positive bias so that the television signals have no influence on the plate current. The synchronisation signals, however, are sufficiently strong to cause a negative tension on the grid and, consequently, a positive peak at the plate of the separating tube.

When individual horizontal and vertical synchronisation impulses are given, the horizontal impulses are very much shorter than the vertical ones. It is thus possible to separate these impulses by means of the resistances R_s and the condensers C_s.

Deflecting Circuit

The deflecting circuit works on the well known principle of charging a condenser through a high resistance and applying the continuously rising potential of the condenser to the deflecting plates of the cathode ray tube. For obtaining a nearly steady increase in this potential and, therefore, a nearly uniform deflection of the spot, two methods are generally used. In one case the condenser is charged through a vacuum tube, giving constant charging current. In the other case, small potential variations are first produced and then amplified. Both methods require additional tubes or apparatus.

The Laboratories circuit uses simple charging resistances, but charges the condensers from the full 4,000 volt anode voltage of the cathode ray tube. Since these condensers merely require charging up to about 500 volts, only the nearly straight part of the charging potential curve is used. The net result is a reduction in the number of tubes and a simplification in the high tension supply.

Fig. 3 shows a schematic arrangement of the charging and discharging circuit, in which the condensers C are charged through resistances R and the gas filled discharging tubes GDT. The separating condensers C_s give the deflecting plates D the required average potential.

A balanced deflecting circuit is used to obtain a rectangular pattern on the high vacuum cathode ray tubes.

Gas discharge tubes of good quality have given satisfactory results, at least with 240 lines.

Fig. 2 includes the complete circuit for horizontal and vertical deflection, the power supply circuit and the connection of the cathode ray tube. The condensers C_1, C_2, C_3, and C_4 are charged by the 4,000 volt source through resistances. Depending upon the grid tensions, the gas discharge tubes GDT_1, etc., break down at a certain tension, thus discharging the condensers through 1,000 ohm protecting resistances. When no synchronisation impulses are given, these discharges happen at somewhat irregular intervals. When, however, synchronisation is applied, the charging and the biasing resistances can be adjusted so that these synchronisation impulses control the operation of the gas discharge tubes.

The discharge of C_1, in the vertical deflecting circuit, causes a positive potential at the cathode of GDT_1. This potential is applied through a condenser to the grid of GDT_2, thus causing the breakdown of the latter tube and the discharge of C_2.

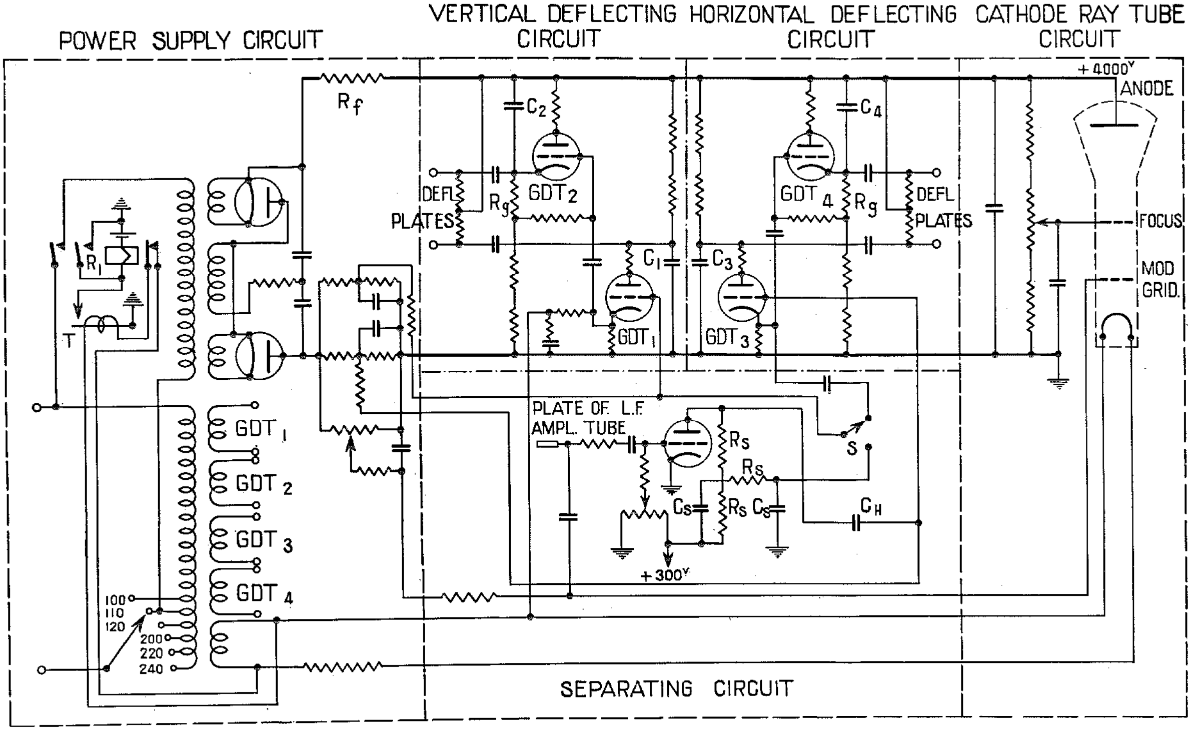

Fig. 2.

The operation of the horizontal deflecting circuit is similar to that of the vertical deflecting circuit. The condensers and resistances are, however, different.

The filament of the cathode ray tube is connected to the filament of GDT_1 in order to obtain a high negative tension on its grid at the moment GDT_1 discharges; that is, at the moment when the spot of the cathode ray tube returns from the bottom to the top of the screen. This negative grid tension avoids a visible return crossing the picture.

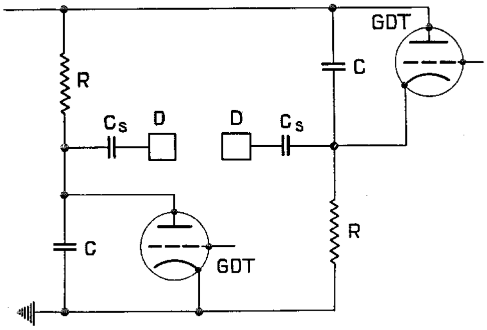

Fig. 3.

To provide for both 180 line and 240 line working, the condensers C_3 and C_4 each consist of two condensers in series, the smaller of which is short-circuited for 180 line reception, while the larger is short-circuited for 240 line reception. For 405 line reception, both condensers are used in series. The switch for making the necessary short-circuits is coupled with a switch, S, which is used for passing from one system of vertical synchronisation to another. The vertical synchronisation of the Eiffel Tower emission is obtained by the suppression of the 180th vertical synchronisation signal. Therefore, the charge of C_3 becomes greater than normal and, when GDT_3 discharges its condenser, a higher potential is obtained at the cathode resistance. This higher potential is applied through a condenser to the grid of GDT_1 which breaks down at this potential, thus causing the vertical return of the spot.

When switching over to 240 or 405 line working for the reception of the Laboratories transmission, which utilises a separate vertical synchronisation impulse, the grid of GDT_1 is connected to the separating circuit in which the vertical synchronisation impulse is separated from the horizontal synchronisation as above described.

Power Supply Circuit for the Cathode Ray Tube and for the Deflecting Circuit

The cathode ray tube used in the set works with an anode tension of 4,000 volts. This tension, which is used also for the deflecting circuit, is obtained by means of the voltage doubler circuit shown in the power supply circuit of Fig. 2.

A separate transformer is used for the filaments of the gas discharge tubes and of the cathode ray tube. As the cathodes of the gas discharge tubes must be hot before applying the high tension, the high tension transformer is connected to the mains about half a minute after connecting the filament transformer. This is accomplished by means of a thermic relay T, the winding of which is heated by the filament transformer. T, in closing its contact, causes the operation of the relay R_1, the winding of which is connected to the grid supply of the visual receiver. R_1 connects the primary of the high tension transformer to the mains, closes a holding circuit for itself, and opens the heating winding of the thermic relay.

In the positive lead, a resistance R_f is introduced for filtering and for adjusting the high tension to the desired value. In the negative lead, a group of resistances is used for obtaining the necessary negative grid tensions for GDT_1 and GDT_2, and for the cathode ray tube.

The grid bias of GDT_2 and GDT_4 is obtained by means of resistances R_g in series with the charging resistances.

Results Obtained

Receivers of the type described have been used in the Laboratories and for several demonstrations with quite satisfactory results. With a field strength very considerably below 1 mV/meter, very stable pictures have been obtained. It is important that the antenna, which may be of the doublet or "Zep" type, be placed at a height appropriate for obtaining the required field strength as well as for protection against outside interference, such as from motor cars.

Power Plants for Rural Full Automatic Offices

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and H. B. LEE,
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1. Introduction

THE advent of the unattended rural automatic exchange has brought with it the necessity for an automatically operated power plant. The reliability of the automatic switching equipment now being used in these small and medium sized offices is such that the associated power plant must be capable of operating satisfactorily for long periods without manual attention.

In a large exchange, the cost of the additional apparatus required for automatic working is small compared with the total cost of the plant, whilst skilled mechanics are immediately available for maintenance purposes. In the case of a rural office, where the outlay on the power plant has to remain more or less in proportion to the number of lines installed, the cost of the additional equipment necessary for automatic operation is a matter which must receive careful consideration. It is also essential that the automatic power apparatus be simple, reliable, and easily adjustable, since, at the rural exchange, skilled attendants are not immediately available.

Several types of the Bell Telephone Manufacturing Company's automatic power plants are in successful operation. In general, these equipments may be divided into two principal classes: the duplicate battery plant and the single battery plant, both including the usual motor generator sets or rectifiers.

The duplicate battery system is becoming more and more restricted to those areas where, during certain hours of the day, the electrical supply is available at a reduced rate. The single battery system, with sufficient battery capacity to maintain the service during a period of power failure, is becoming increasingly popular, both on account of its lower initial cost and its higher efficiency, particularly when operating on a full float basis.

2. General Requirements for Power Plants in 7-D Rotary Offices

Reliable operation of automatic exchanges is only guaranteed when the voltage of the feeding current is kept within certain limits. For rural exchanges, the following limits are fixed:

7-D center type exchange—minimum 44, maximum 52 volts;
7-D district exchanges—minimum 44, maximum 54 volts.

The above limits are to be taken as applying at the circuit fuses of the automatic switching equipment. For small exchanges where there is, as a rule, practically no distance between the battery, the power board, and the circuit fuses, the minimum battery voltage may correspond to the minimum limit fixed for the operation of the equipment. For medium and large sized offices, the minimum permissible limit at the discharge fuses on the power board must be kept above the minimum equipment limit by the amount of voltage drop allowed in the discharge feeders. This drop is fixed at 2 volts when the feeders carry current used for signaling purposes only, or for talking and signaling combined, where the microphones are fed over retardation coils. For talking circuits using repeating coil transmission the permissible drop is limited to 0.5 volt.

During discharge the voltage of the lead-acid battery falls from 2 to approximately 1.83 volts per cell, and the minimum number of cells required in a battery is therefore fixed at:

$$\left.\begin{array}{l} \dfrac{48}{1.83}=26\text{ cells} \\[2ex] \dfrac{46}{1.83}=25\text{ cells} \\[2ex] \dfrac{44}{1.83}=24\text{ cells} \end{array}\right\} \begin{array}{l}\text{For exchanges where} \\ \text{the voltage should} \\ \text{not drop below}\end{array} \quad \begin{array}{r} 48\text{ volts} \\[4ex] 46\text{ volts} \\[4ex] 44\text{ volts}\end{array}$$

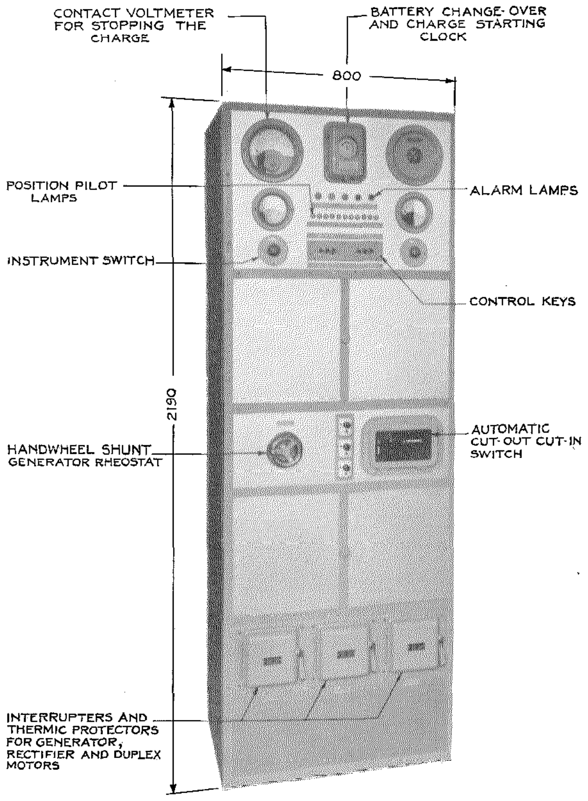
CONTACT VOLTMETER FOR STOPPING THE CHARGE
BATTERY CHANGE-OVER AND CHARGE STARTING CLOCK
800
POSITION PILOT LAMPS
ALARM LAMPS
INSTRUMENT SWITCH
CONTROL KEYS
2190
AUTOMATIC CUT-OUT CUT-IN SWITCH
HANDWHEEL SHUNT GENERATOR RHEOSTAT
INTERRUPTERS AND THERMIC PROTECTORS FOR GENERATOR, RECTIFIER AND DUPLEX MOTORS

Fig. 1—All Metal Powerboard.

The voltage of these batteries when charged in the normal manner rises to 65, 67.5, or even 70.2 volts. Unless, therefore, some form of voltage regulation is provided, the battery must be disconnected from the load whilst charging, thus necessitating a duplicate battery arrangement.

3. *Duplicate Battery Arrangement*

The duplicate battery arrangement requires two batteries, one of which is charged, whilst the other is discharged. The charging generators or rectifiers need not be of the telephone type for this service.

Duplicate battery systems are used with semi-automatic and with full automatic operation. Plants which are entirely manually operated are of no use in automatic rural offices.

With semi-automatic operation, the batteries are changed over and the charging plant is started by the attendant. On the completion of the charge, as indicated by a contact voltmeter or an ampere hour meter, the charging generator or rectifier is automatically disconnected. With full automatic operation, the changeover of the batteries can be controlled by the voltage of the battery feeding the equipment. This voltage, however, depends on the rate of discharge at any particular moment, so that it is preferable to interchange the batteries after a predetermined number of hours of service. Provision is made for placing the used battery on charge as soon as it is disconnected from the exchange.

Figs. 1 and 2 show an all metal power board designed for a full automatic, duplicate battery arrangement, operated on the charge-discharge principle. The board is designed for a maximum discharge current of 100 amperes. The two batteries are interchanged at a predetermined time under the control of an electrically wound clock, which also starts the charging generator and connects it to the discharged battery. The charge is terminated by the operation of a contact voltmeter, set to close at the maximum voltage which should be reached with the battery fully charged.

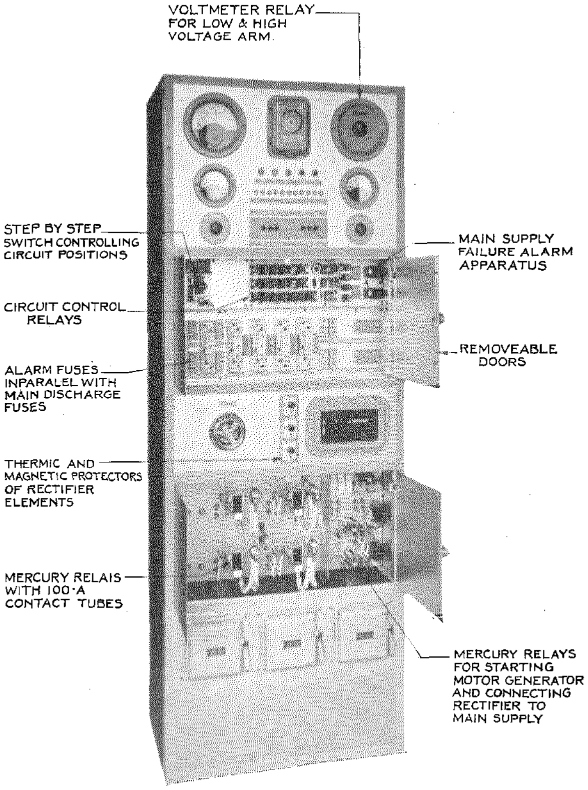
VOLTMETER RELAY FOR LOW & HIGH VOLTAGE ARM
STEP BY STEP SWITCH CONTROLLING CIRCUIT POSITIONS
MAIN SUPPLY FAILURE ALARM APPARATUS
CIRCUIT CONTROL RELAYS
REMOVEABLE DOORS
ALARM FUSES INPARALEL WITH MAIN DISCHARGE FUSES
THERMIC AND MAGNETIC PROTECTORS OF RECTIFIER ELEMENTS
MERCURY RELAIS WITH 100-A CONTACT TUBES
MERCURY RELAYS FOR STARTING MOTOR GENERATOR AND CONNECTING RECTIFIER TO MAIN SUPPLY

Fig. 2—All Metal Powerboard (Doors Open).

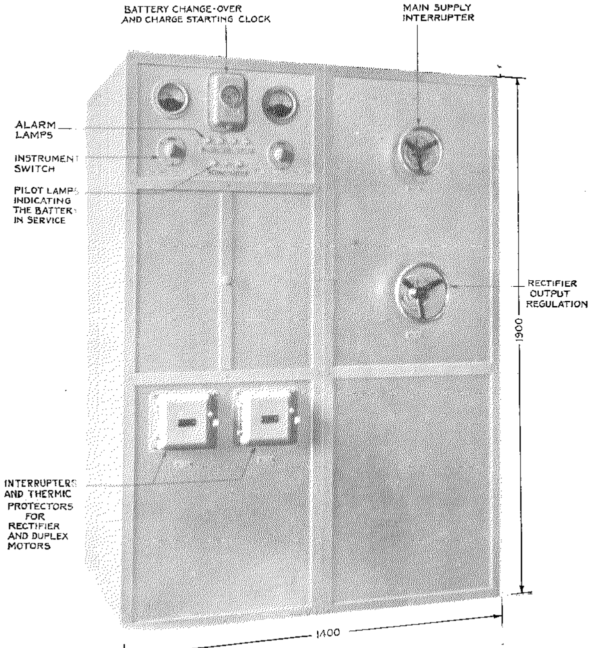
BATTERY CHANGE-OVER AND CHARGE STARTING CLOCK
MAIN SUPPLY INTERRUPTER
ALARM LAMPS
INSTRUMENT SWITCH
PILOT LAMPS INDICATING THE BATTERY IN SERVICE
RECTIFIER OUTPUT REGULATION
1900
INTERRUPTERS AND THERMIC PROTECTORS FOR RECTIFIER AND DUPLEX MOTORS
1400

Fig. 3—Another Type of Automatic Duplicate Battery Arrangement.

When desired, during the day the battery which is being discharged may be floated by means of a Selenium rectifier. By operating appropriate keys the batteries may be interchanged manually, connected in parallel for emergency discharge, or floated in parallel. The arrangement is such as to prevent incorrect operation, whilst the pilot lamps are fitted to indicate the particular circuit condition which exists.

Another type of automatic duplicate battery arrangement is shown in Figs. 3 and 4. In this case the charging current is supplied by a 40 ampere hot cathode rectifier. The changeover is again controlled by an electric clock, but, in addition, provision is made such that, should the voltage of the discharging battery fall too low, the changeover would operate and the discharged battery would immediately be put on charge.

4. Single Battery Arrangement

4.1 GENERAL CONSIDERATION

As mentioned previously, the voltage of a lead-acid battery rises to 2.7 volts per cell when charged in the normal manner. This does not mean that a battery cannot be fully charged without reaching this voltage. The voltage of a cell towards the completion of the charge is a function of the charging current. Provided the charging rate is sufficiently reduced and the charging time increased to correspond, a battery may be fully charged without the voltage exceeding 2.4 volts per cell, but it takes about 160 hours to complete the charge if a current of constant value is used.

Referring in particular to the Belgian Tudor Planté cell, Fig. 5 shows the capacity at various discharge rates; and, for the different charging rates, the state of charge of Planté type cells when the tension reaches 2.16, 2.2, 2.25, 2.3, and 2.4 volts. The curves are taken at 15° C. with an electrolyte of specific gravity 1.200 (24° Baumé) when fully charged. The cells used were fitted with wooden separators.

The different equipment requirements and battery characteristics for 7-D office power plants are as follows:

	Center Type Exchange	District Type Exchange
(*a*) Maximum voltage	52 volts	54 volts
(*b*) Minimum voltage at circuit fuses.	44 volts	44 volts
(*c*) Minimum number of cells if drop in feeders can be neglected	24 cells	24 cells
(*d*) Minimum number of cells if 2 V. drop in the feeders is to be considered	25 cells	25 cells
(*e*) Maximum permissible tension per cell with a 24 cell battery when no C.E.M.F. cells are connected in the discharge	2.16 V.	2.25 V.
Same with 25 cells	2.08 V.	2.16 V.
(*f*) Approximate percentage of full charge capacity which can be restored to a battery without exceeding the maximum tension per cell with the intensity of the charging current reduced to a 10 hour value—24 cell battery	49%	71%
(*g*) Same for 25 cell battery	—	49%
(*h*) Same for 24 cell battery with charging current reduced to 20 hours value	61%	78%
(*i*) Same for 25 cell battery with charging current reduced to 20 hour value	—	61%

The above tabulation shows that the battery in 7-D rural exchanges cannot be charged 100% without exceeding the voltage limits, even when these are as wide as 44–54 volts, if a recharge of the battery is desired within 20 hours after a full discharge.

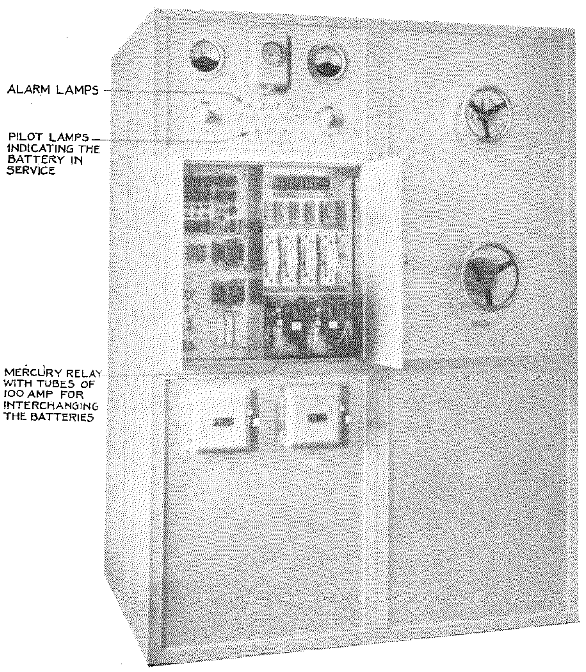
ALARM LAMPS
PILOT LAMPS INDICATING THE BATTERY IN SERVICE
MERCURY RELAY WITH TUBES OF 100 AMP FOR INTERCHANGING THE BATTERIES

Fig. 4—Another Type of Automatic Duplicate Battery Arrangement.

The simplest method of feeding an exchange by means of a single battery is to employ a battery of large size, such that when charged to only about three-quarters of its full capacity, there is sufficient reserve to feed the equipment during power failures. This arrangement may be used either with or without controlled charge.

With controlled charge, a voltage relay cuts off the charge when the battery voltage reaches the upper limit and reconnects the charging supply when the voltage has dropped to about 2 volts per cell. Alternatively, the charge may be controlled by means of a double wound choke coil, one winding of which is connected in the primary supply to the charging rectifier, whilst the second winding carries the d-c. output. This automatic choke-controlled rectifier is described in more detail later, but it must be pointed out here that the output of such a rectifier is affected to a considerable extent by the voltage variations of the main supply.

With uncontrolled charge, the charging current is adjusted so that the input to the battery over a given period corresponds to the average current requirements of the exchange plus the losses in the battery.

In practice the uncontrolled charge consists in floating the battery with a current of a value such that the voltage is maintained between 2.18 and 2.3 volts per cell, depending on the temperature and the type of plates used. In rural offices, where the tension of the main supply is as a rule unstable and power failure much more frequent than in larger centers, the regulation of such a plant presents many difficulties.

4.2 Rectifier Operated Single Battery Full Float Plants

In district exchanges there are usually several hours per day when there is practically no traffic. It is, therefore, possible to charge the battery up to the 54 volt limit and to continue beyond this point provided arrangements are made to suspend charging temporarily whilst a call is in progress. Immediately the charge is stopped the voltage falls within the required limits and, when the call is terminated, the charging current can be reestablished.

When the charging is adjusted to a 10 hour rate value, about 71% of the full charge capacity can be restored to the battery in district offices before the 54 volt limit is reached. Beyond this point the charge should be continued with the current reduced to a trickle charge value in order to avoid over-formation of the positive plates.

A system making use of the above principles has been found to give excellent results in small 7-D offices. The method of operation, prepared in bulletin form by the Bell Telephone Manufacturing Company, Antwerp, on the 7-D Rotary Automatic Telephone System, may be summarised as follows:

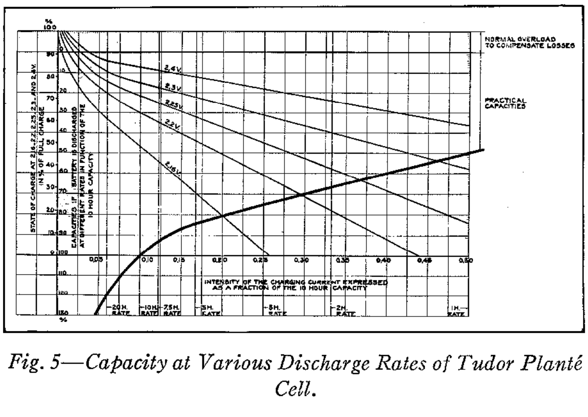

Fig. 5—Capacity at Various Discharge Rates of Tudor Planté Cell.

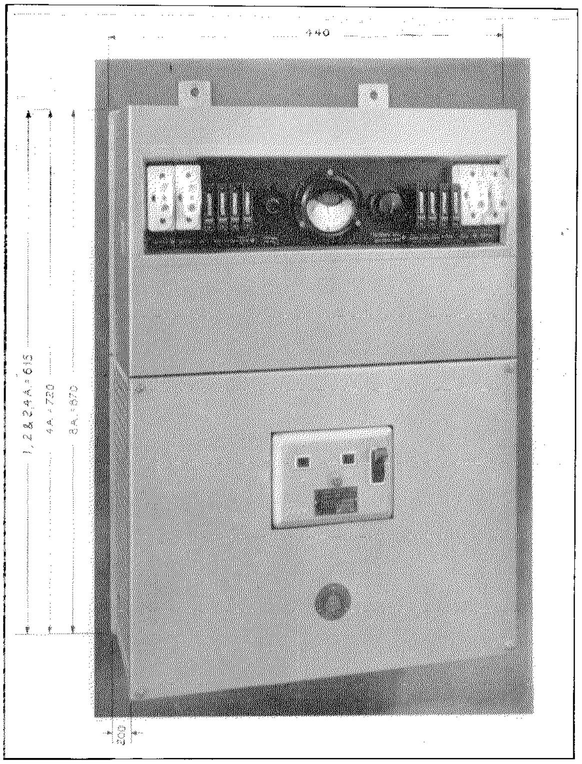

Fig. 6—Antwerp Power Units.

Direct current, with a sufficiently low ripple, is obtained from a Selenium rectifier provided with smoothing choke and dry electrolytic condensers. This current is fed via two adjustable resistances, one resistance regulating the normal charging current and the other, the trickle charge. The main charge is controlled by voltage relays arranged so that this circuit is interrupted only when the voltage rises to 54 and is reestablished when it falls to 50 volts. Calls going through the exchange open the trickle charge circuit but not the main circuit. The arrangement therefore permits the rectifier to deliver current at the full rate until the voltage limit is reached. Beyond this point, the charge is continued at the trickle charge rate when no calls are in progress. An alarm is arranged to operate when the main supply is interrupted, or when the voltage falls below a predetermined limit.

The relays may be mounted either with the automatic equipment or with the rectifier. The power units recently standardised by the Bell Telephone Manufacturing Company are arranged so that the rectifier with its overload protection, the control relays, the combined volt and ammeter, together with the fuses, etc., are all contained in a single unit, as illustrated in Figs. 6 and 7. They show a rectifier built for outputs of 1.2, 2.4, 4.0, and 8.0 amperes at 44 volts. Fig. 8 shows the output curve of the 2.4 ampere rectifier.

4.3 Full Automatic Plants with Ampere Hour Meter Control

A type of power plant which has been in satisfactory operation for many years, both in Europe and in the United States, and is being adopted by the British Post Office, is one which makes use of a special ampere hour meter connected in the battery lead. When the battery has been discharged some 10%, the ampere hour meter makes contact and starts the charging apparatus, which continues to supply current until the battery is again fully charged. This type

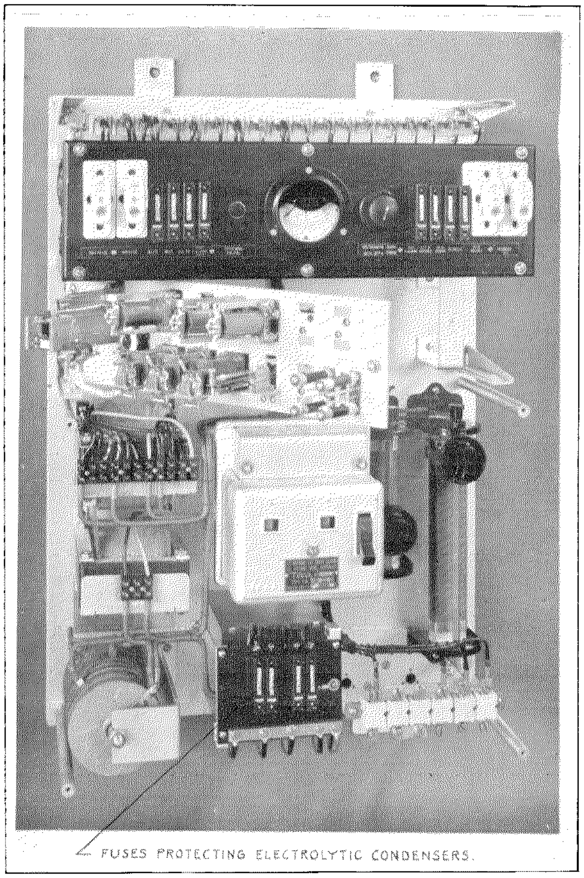

Fig. 7—Antwerp Power Units.

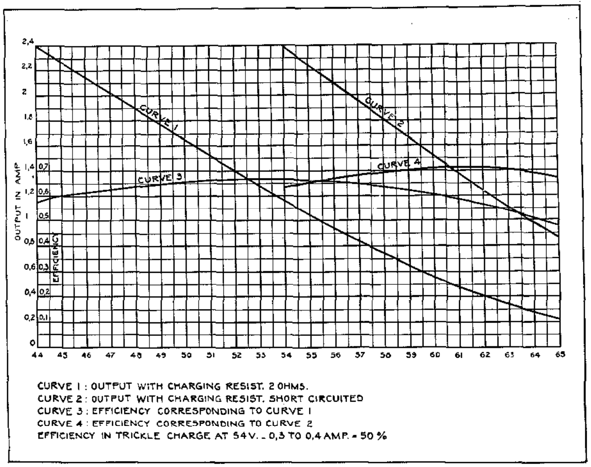

Fig. 8—Output Curve of 2.4 Ampere Rectifier.

of plant cannot, strictly speaking, be described as full floating in operation but, since the charging plant normally starts in the morning when the traffic is increasing, the greater portion of the load is supplied by the machine or rectifier and not by the battery. In addition to the contacts for stopping and starting the charge, a third contact gives an alarm when the battery is discharged more than 35%. The ampere hour meters used read correctly in the discharge direction but in the reverse, or charge direction, the reading is low by an amount which can be varied from 10% to about 40%, thus enabling the excess of charge over discharge to be adjusted to allow for the losses in the battery.

Figs. 9 and 10 illustrate a power board designed for a single battery plant with ampere hour meter control, the current being supplied by a Selenium rectifier. This type of board is suitable for exchanges with a maximum current drain of 100 amperes.

It is essential that the output of the rectifier be sufficient to make good, every 24 hours, the total drain to the exchange plus the losses in the battery but, in order to provide for the necessary reserve and quick recharge, it is usual to specify a rectifier having an output at least equal to the maximum drain.

In order that the battery may be charged to its full capacity, C.E.M.F. cells are connected in the discharge lead under the control of a contact voltmeter which also short-circuits these cells when charging ceases.

The same arrangement can be used when a charging generator is used in place of a rectifier, but in this case it is slightly more complicated. In addition to starting the motor, it is necessary to connect the generator to the battery as the voltage builds up, and to provide protection against current reversal.

In order to somewhat simplify the arrangements, a scheme has been developed which dispenses with the contact voltmeter or voltmeter relay by making use of a generator compounded to give a practically constant voltage from no load to full load (±3% tolerance). When the generator is floating a battery, the series winding is not connected between the armature and the battery but is inserted in the discharge lead in order to prevent the possibility of a current reversal and to ensure that the increase in generator field flux is proportional to the current taken by the equipment, thus maintaining a constant voltage irrespective of the load.

In practice it is usual to arrange for only a portion of the load to pass through the series winding by connecting it in parallel with

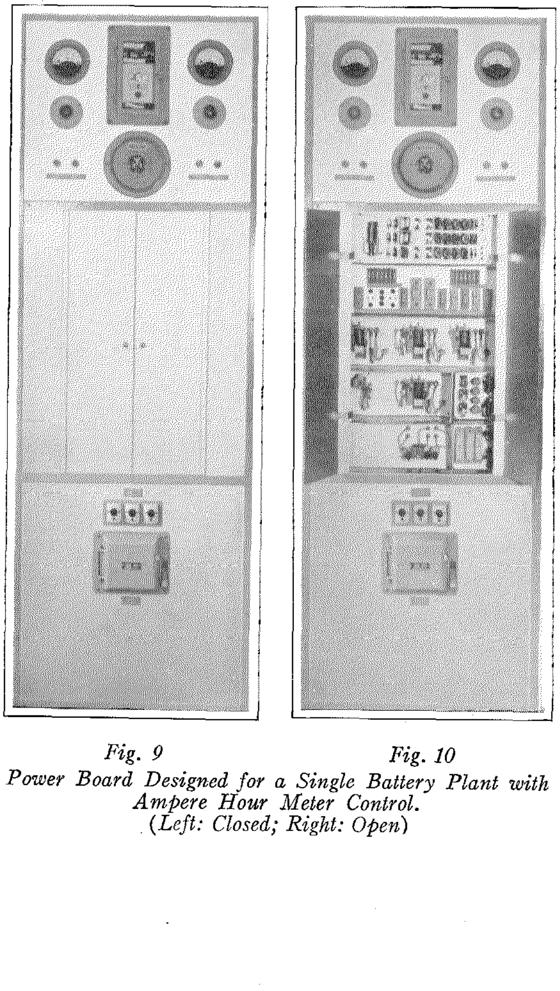

Fig. 9 *Fig. 10*

Power Board Designed for a Single Battery Plant with Ampere Hour Meter Control.
(Left: Closed; Right: Open)

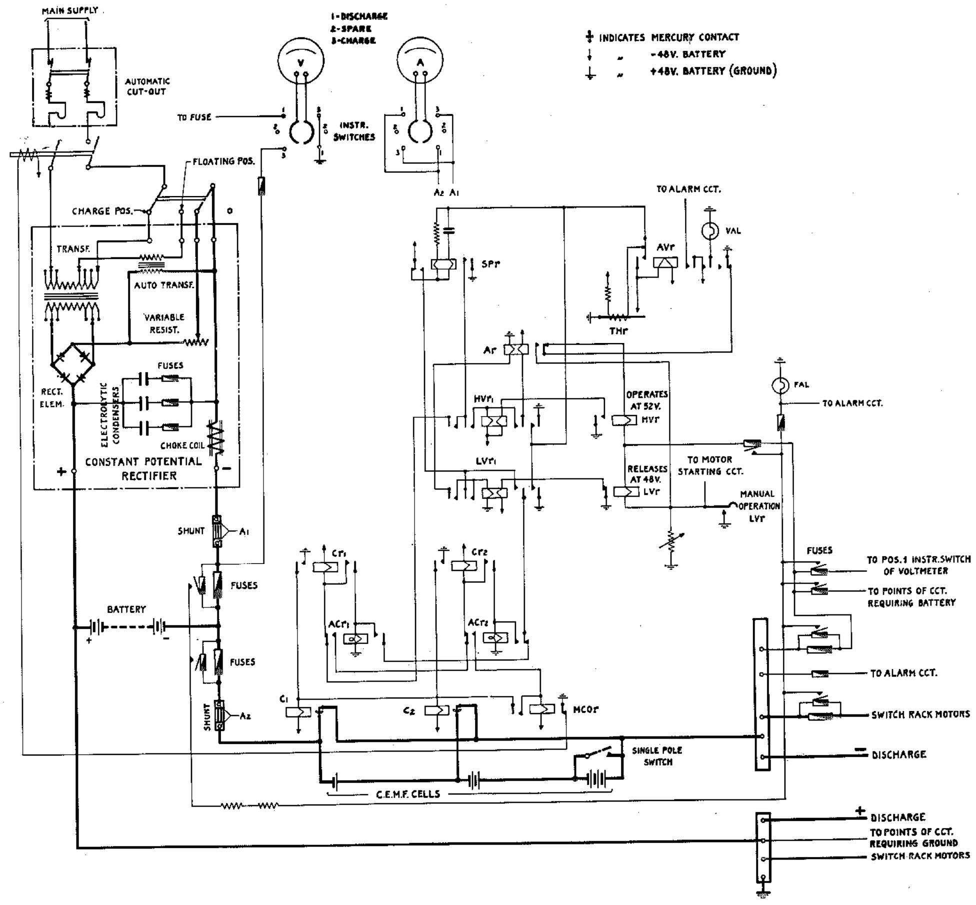

Fig. 11—Typical Circuit Arrangements.

an adjustable non-inductive shunt. With this scheme, the ampere hour meter closes the circuit for starting the generator when the battery has been discharged 10%, just as in plants previously described. The generator is adjusted to give 2.25 volts per cell of the battery at an output corresponding to the drain of the equipment plus the losses in the battery. When the generator is connected to the battery, a C.E.M.F. cell is introduced simultaneously into the discharge lead, thus permitting the battery voltage of the 24 cell battery in center exchanges to be increased to 54 volts. When the current taken from the battery plus the losses has been restored the ampere hour meter stops the charge. Since with one C.E.M.F. cell the battery voltage is limited to 2.25 volts per cell, the arrangement does not permit the battery to be fully charged. Where it is desired to charge the battery more fully, two C.E.M.F. cells must be introduced at the same time in order that the battery voltage may be increased to 56 or 2.33 volts per cell.

Such plants require a full charge up to 2.7 volts per cell about every two months. This is made possible by connecting C.E.M.F. cells in the discharge lead to the exchange.

4.4 Full Float Plant with Constant Potential Rectifier

The term "constant potential rectifier" is used to describe a rectifier constructed so that its

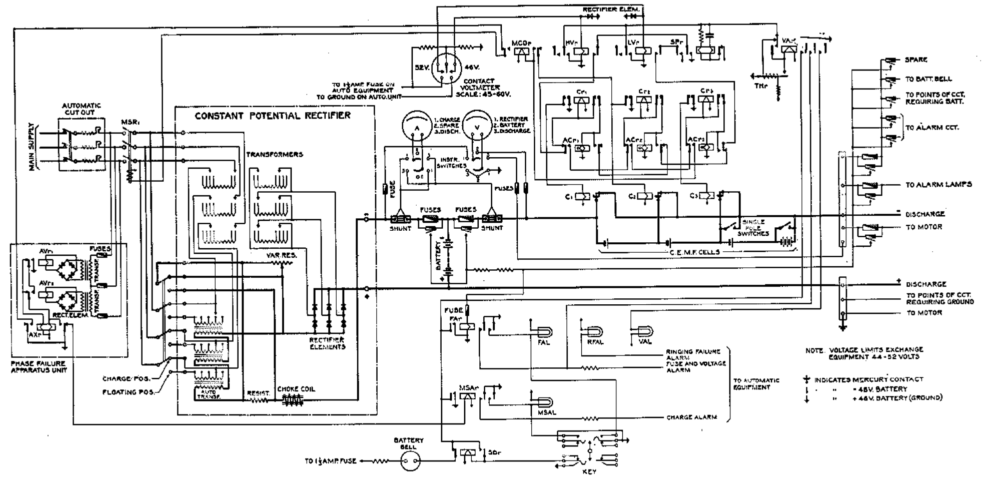

Fig. 12—Typical Circuit Arrangements.

output is in large measure dependent on the battery voltage. When the battery voltage is low the rectifier charges the battery in the usual manner, the voltage gradually rising as the charge progresses, until at a certain predetermined battery voltage the charging current suddenly falls to a mere trickle. The trickle charge continues until the current requirements of the exchange are such as to cause the voltage of the battery to fall to a second and somewhat lower predetermined value when current suddenly reverts from the trickle to the full charge rate. This self-regulating feature is obtained by connecting one winding of a double wound choke in series with the primary of the transformer, and the second winding in series with the d-c. output (Figs. 11 and 12). The impedance of the a-c. winding of the choke depends on the state of magnetic saturation of the core, and this in turn depends on the value of the current in the d-c. winding. As the battery voltage rises during charge the current falls slightly until a point is reached where the current passing through the d-c. winding is no longer sufficient to completely saturate the iron core. The impedance of the a-c. winding now begins to increase with the result that the voltage applied to the transformer primary is reduced, still further reducing the output of the rectifier. The net result is that, once the critical battery voltage is reached, the arrangement becomes unstable and the current falls to perhaps a tenth or less of its former value. The reverse action takes place and the current reverts to its former full charge value when the exchange load has caused the battery voltage to fall sufficiently. The degree to which the battery is charged depends on the value at which the rectifier is adjusted to revert to trickle charge. If this upper voltage limit is set at 52 or 54 volts the battery cannot be fully charged. This incomplete charging is a serious feature at rural exchanges since most Administrations and operating companies prefer power plants which operate with the batteries in a fully charged condition.

It is therefore clear that a constant potential rectifier, in spite of the additional auto-regulation coil, is not capable of maintaining the battery in a fully charged condition at all times even if the main voltage variations are within ±5%. If this condition has to be met, it is necessary to provide voltage control which prevents excessive voltage at the exchange busbar and which permits charging of the battery to continue even when the main supply is at minimum voltage.

In certain rural areas main supply voltage variations of ±5% are normal, whilst variations of ±10% are met with in other areas. Since the output of the rectifier bears a direct relation to the main supply voltage, a rectifier which is adjusted to cut off at 54 volts when the supply is 5% above normal will give practically no output at 50 or 51 volts when the main supply is 5% below normal.

To avoid the above mentioned difficulty, the constant potential rectifiers furnished in power plants of rural exchanges are preferably designed to cut off at 54 volts when operating on the minimum supply voltage, thus ensuring that the battery will be adequately charged under all conditions. In order that the exchange voltage may not be excessive when the mains voltage is high, and to enable the battery to be charged to its full capacity, provision is made for the automatic introduction of C.E.M.F. cells into the discharge lead under voltage operated control. Provision is also made for adjusting the trickle charge current by shunting the d-c. winding of the choke coil with an adjustable non-inductive resistance, whilst in order to facilitate the first charge and to permit of a specially quick recharge after a prolonged power failure, it is possible to render the constant potential feature entirely non-operative.

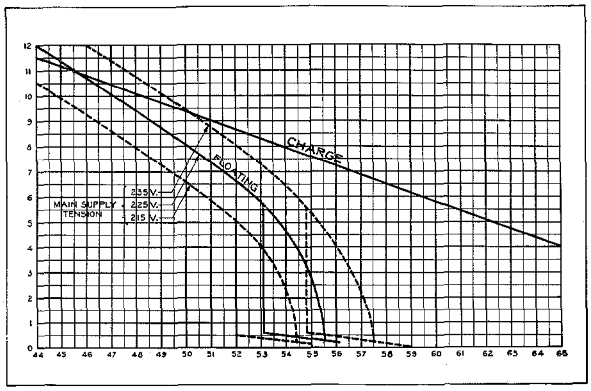

Fig. 14—Output Curve of Power Plant of Fig. 13.

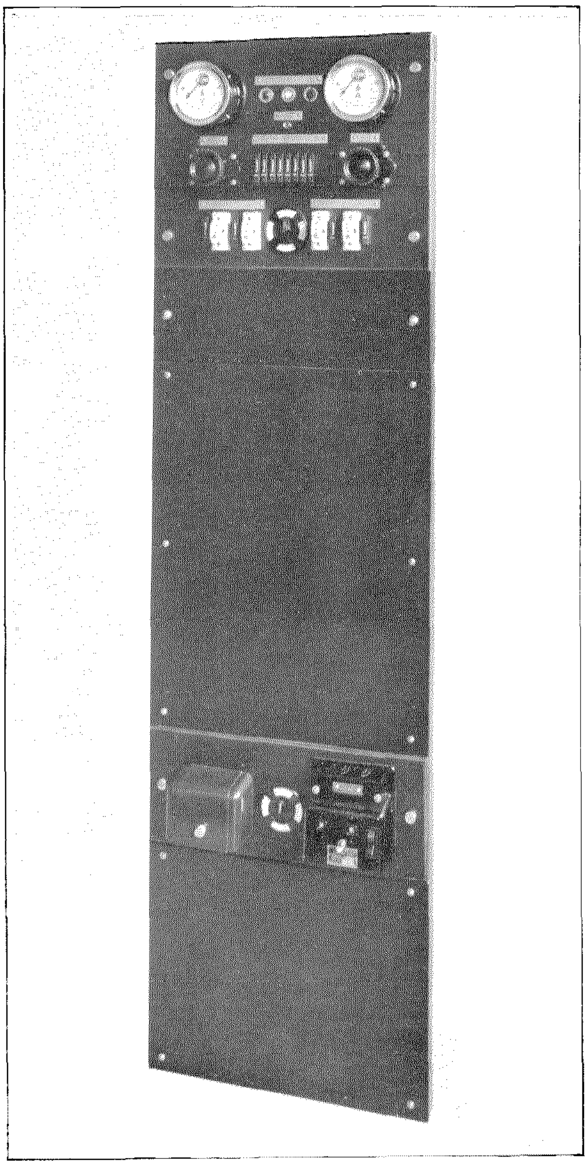

Fig. 13—Power Plant with a Circuit in Accordance with Fig. 11.

Two of the typical circuit arrangements are shown in Figs. 11 and 12. In one case (Fig. 11) the introduction of C.E.M.F. cells is controlled by voltage relays of the telephone relay type. In the other case (Fig. 12) the C.E.M.F. cells are under the control of a contact voltmeter or voltmeter relay. The former circuit is used for the smaller, and the latter circuit for the larger plants. Both schemes are reliable, but whilst the contact voltmeter is easier to adjust and more accurate than the voltage relay, its greater cost is a serious matter in the smaller plants. Moreover, since great accuracy is not essential, it is possible that the voltage relay system may eventually be employed, irrespective of the size of the equipment.

In both circuits the C.E.M.F. cells are introduced in successive stages, and when all the cells are in circuit and the exchange voltage again reaches the upper limit, the rectifier is disconnected from the supply, to be reconnected only when the exchange load has caused the voltage to fall to a predetermined limit. Both circuits make

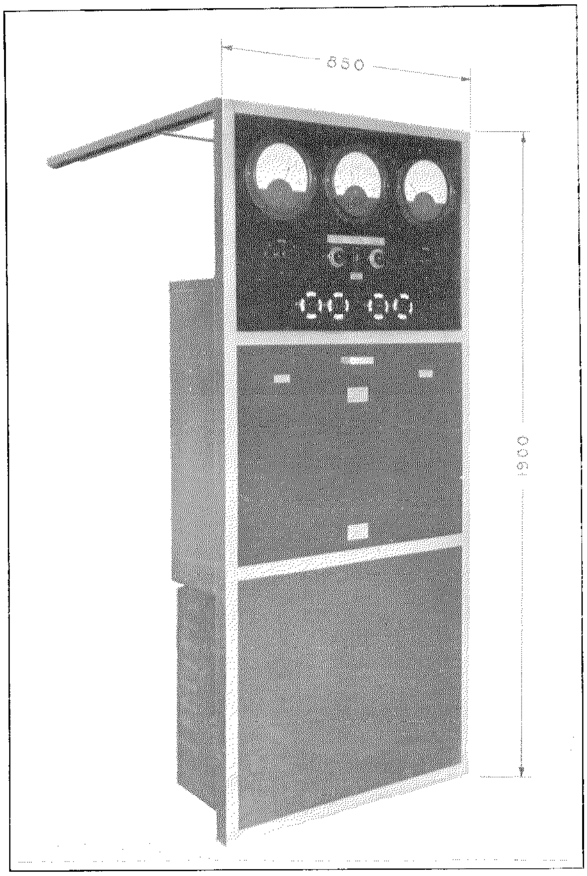

Fig. 15—Power Plant with a Circuit in Accordance with Fig. 12.

provision for cutting out the constant potential choke for the purpose of initial charge, or quick recharge, and terminals are also provided for connecting additional C.E.M.F. cells to enable the battery to be charged to 2.7 volts per cell on occasion. These additional C.E.M.F. cells are usually of the portable type, and are as a rule common to a whole rural area. Facilities are also provided for connecting an emergency charging plant for use in the case of breakdown or extensive repairs.

Fig. 13 shows a power plant with a circuit in accordance with Fig. 11 and equipped with a 12 ampere single-phase rectifier, the approximate output curve of which is given in Fig. 14.

In general, three-phase rectifiers are used for the larger outputs. Figs. 15 and 16 illustrate a powerboard with a circuit in accordance with Fig. 12. This board is of the all metal type. Fig. 17 shows one on which all the equipment, excluding only the rectifier and the telephone type relays, is mounted on slate panels. The layout of the equipment on both types of boards is such that it can be used for offices with a maximum drain of 100 amperes. In order to reduce the initial cost it is usual to supply one rectifier only at the outset, but provision is made for connecting a second rectifier when required. This second rectifier, not shown on the circuit, is connected to the mains only when a current relay in the discharge lead indicates that one rectifier alone is insufficient to carry the load.

In general, a rectifier is chosen of sufficient output to carry the full busy hour drain normally required by the exchange equipment, in which case the full battery capacity is always available. As an alternative it is practicable to use a rectifier which, during the busy hour, supplies only a portion of the total current, the remainder being furnished by the battery which is recharged

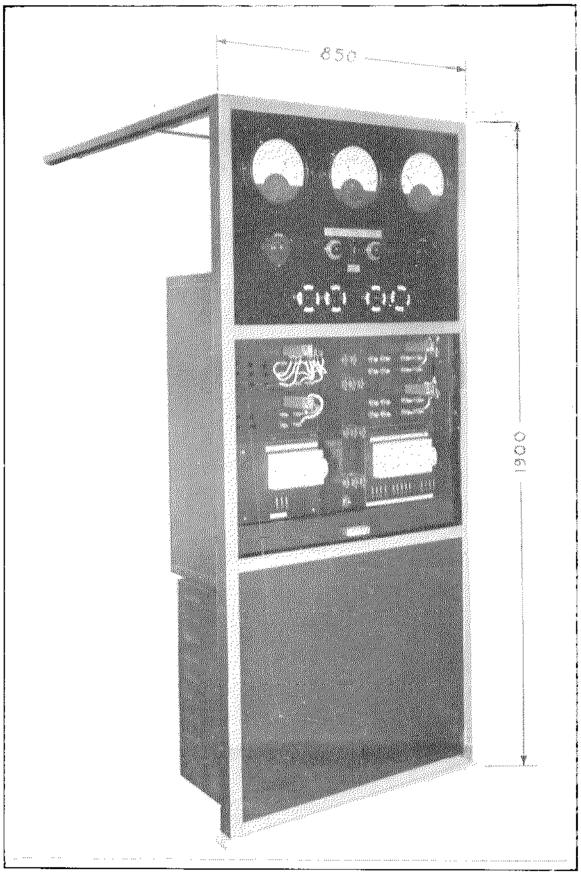

Fig. 16—Power Plant with a Circuit in Accordance with Fig. 12.

during the slack period. The capacity of the battery, however, must be such as to provide adequate reserve should a power failure occur immediately after the busy period of the day when the cells have already to some extent been discharged.

5. *Power Plants for Use on D-C. Systems*

Where a direct current supply with the positive pole earthed is available, the simplest arrangement is to charge the battery directly from the mains with a suitable resistance in series to reduce the current to the correct value. Whether a motor generator is used in preference to this simple direct charging scheme depends largely on the voltage of the d-c. supply. In areas where the supply is 220 volts, 3-wire, with the neutral earthed, the battery can be charged between the 110 volt negative pole and the earthed neutral. The efficiency of this arrangement is about 50%, which is equal to that obtained with a small motor generator, the efficiency of which is between 45% and 60%. Direct charging from the mains is therefore recommended when a 110 volt supply is available, the charge being preferably controlled by two resistances in parallel as described above. When the supply voltage exceeds 110, or the negative pole is earthed, a motor generator must be used. A method of control which gives satisfaction is the one whereby the motor generator is started when an ampere hour meter registers a discharge of 10% of the battery capacity, the charge being continued until the meter indicates that the battery is again fully charged. C.E.M.F. cells must be introduced into the discharge lead under the control of a contact voltmeter, in order to maintain the voltage at the exchange within the permissible limits during the charging period. This method is one which is not affected to any serious extent by variations in the supply voltage.

In order to reduce the first cost it is possible to use the compound generator arrangement, in which one or more C.E.M.F. cells are introduced into the discharge circuit at the same time that the generator is connected to the battery. The speed of the motor generator is, however, affected by variations in the supply voltage, and this in turn causes variation in the output of the generator. It would, therefore, be necessary to use an automatic speed regulator on the motor, an addition which possibly would not be sufficiently reliable for use in an unattended exchange. The arrangement is therefore less desirable for rural exchanges.

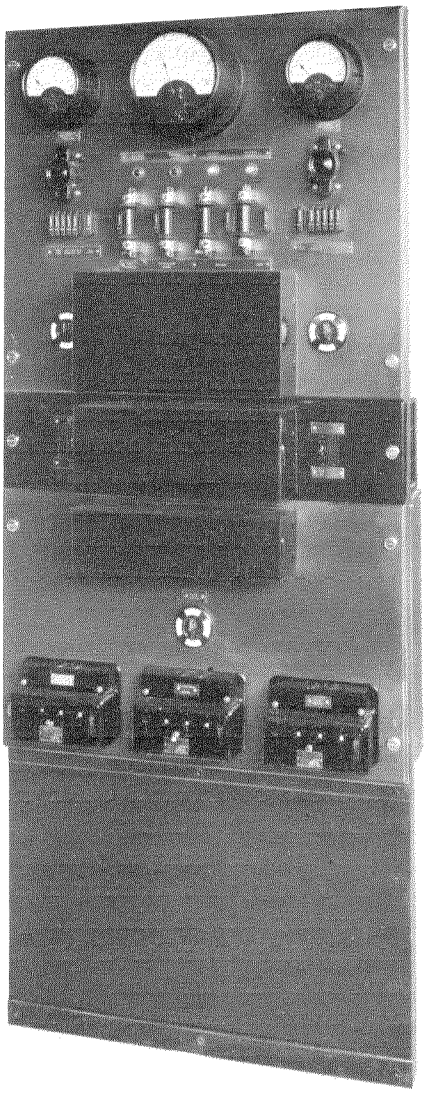

Fig. 17—Power Plant with all Equipment on Slate Panels.

It has been found possible to dispense with the ampere hour meter by making use of a contact fitted on a clock. This contact starts the charge at a predetermined hour each day. It is preferable to arrange for the charging to take place during the busy hours, since this will ensure that the major portion of the current required by the exchange is furnished directly by the generator. Once started, the charge continues until the voltage of the battery indicates that it is fully charged. C.E.M.F. cells are introduced one at a time, the first when the generator is connected to the battery. Additional C.E.M.F. cells are then added under the control of a contact voltmeter or voltage relay whenever the voltage at the exchange reaches the maximum limit.

6. Large Rural Exchanges

All the power plants thus far described are intended for use in unattended exchanges having a maximum busy hour drain not exceeding 100 amperes. For larger exchanges where the drain exceeds 100 amperes the requirements, generally speaking, are similar, but the number of such types of power plant is so considerable that anything approaching a complete description would be beyond the scope of this article. It may be of interest, however, to mention that the Bell Telephone Manufacturing Company has recently developed a full automatic operated, full float plant embodying the following features:

(1) The plant can be operated either on a full float or semi-full float basis;

(2) Single battery with emergency end cells, the latter used only when floating is stopped. The emergency cells are trickle charged from a small Selenium rectifier if the plant is operated on a full float basis;

(3) Motor generators are used for floating or charging the battery. The voltage of these generators is regulated automatically by means of motor driven rheostats;

(4) The number of generators which can be used in parallel is not limited. They are started and connected to the battery, or stopped, as required, in order to keep the battery at the floating voltage, i.e., between 2.1 and 2.2 volts per cell. All the generators in service, except the last one started, run at full load, the load variations being taken by the last machine;

(5) For the purpose of giving a maintenance charge, it is possible to float at a voltage higher than 2.15 volts per cell by introducing C.E.M.F. cells manually into the battery discharge lead;

(6) The type of generator used is such that, with the addition of electrolytic condensers, the exchange can be fed directly from the generators with the battery entirely disconnected.

It should be mentioned that the operation of an exchange without a battery is not considered advisable. If it is necessary to disconnect the single battery for repair, extension, or any other reason, it is preferable to provide an emergency battery, consisting possibly of car starter batteries. If this precaution is not taken, the slightest interruption in the main supply will result in the loss of all the exchange connections, with the probability of serious overloading when the supply is reestablished. In the larger exchanges it is the usual practice to arrange for the single battery to consist of two or more "strings" of cells connected permanently in parallel but arranged so that one "string" may be disconnected at a time for maintenance or repair.

Public Address Installation for the Performances of "Le Vray Mistère de la Passion" on the Place Du Parvis in Front of Notre Dame Cathedral, Paris

By G. MEUNIER
Le Matériel Téléphonique, Paris, France

General

Magnitude of the Performances

To make use of one of the principal Paris public squares—150 metres long, 90 metres wide—as an open air theatre; to erect thereon a metallic flooring, rising from the ground level progressively up to 12.50 m., for the seating accommodation of an audience of more than 10,000 people, with the safety, exits, visibility, and comfort of the best theatres; to present the foremost French actors, assisted by a chorus of 1,500 and the Republican Mounted Guards on a stage 50 metres long by 25 metres wide; to provide a spectacle having the magnitude and solemnity of Notre Dame Cathedral as an incomparable scenic background—such, for the past two years, has been the principal achievement of the Comité des Fêtes de Paris on the initiative of the great promoter of open air theatricals: Pierre Aldebert. The production, "Le Vray Mistère de la Passion," harmonising perfectly with the surroundings, virtually makes these performances the chief attraction of the "Fêtes de Paris," held in the beginning of June of each year.

Enumeration of the many difficulties encountered in the realisation of this gigantic chef-d'oeuvre and the manner in which they were overcome will not be attempted in this paper. It will readily be appreciated, however, that immobilisation for a period of three weeks of the whole of an important and busy district of Paris, necessitating diversion of the heavy street traffic, and the coordination of stage mob movements on a vast scale with accompanying sound and lighting effects were tasks not easily accomplished. Similarly, the erection in record time, of scaffolding capable of supporting, with the requisite safety factor, such a considerable audience, and the transformation of an historical monument like Notre Dame into a theatrical scene without hindrance to the regular religious ceremonies, involved technical and administrative problems which required most effective resolution by the organisers and their collaborators.[1]

In installations of this character, two essential elements, obviously, are the lighting effects and the sound reproduction.

Scenic Dispositions

In order that the importance of the difficulties encountered in achieving scenic effects may be realised, it is necessary to note the particular circumstances accentuating them.

In addition to the dimensions of the public auditorium and of the stage, the latter was especially unfavourable to the placing of projectors, loudspeakers, or microphones, due to the absence of girders, columns, rails, etc. The stage, in fact, consisted of a plain, practically bare surface, showing the Cathedral façade almost in its entirety, and was surrounded on three sides with access slopes intended, in certain parts of the play, to permit a merging of performers and spectators. Some of the scenes—the Prologue and the Bearing of the Cross—were played off-stage, such as in the passage separating the stage from the spectators.

The rear of the stage was lined on the left and right by two walls, 3 metres high, with two kinds of thrones representing "mansions," which harmonised with the Cathedral and which resembled the theatrical effects of the middle ages. The central portion disclosed, according to the scene,

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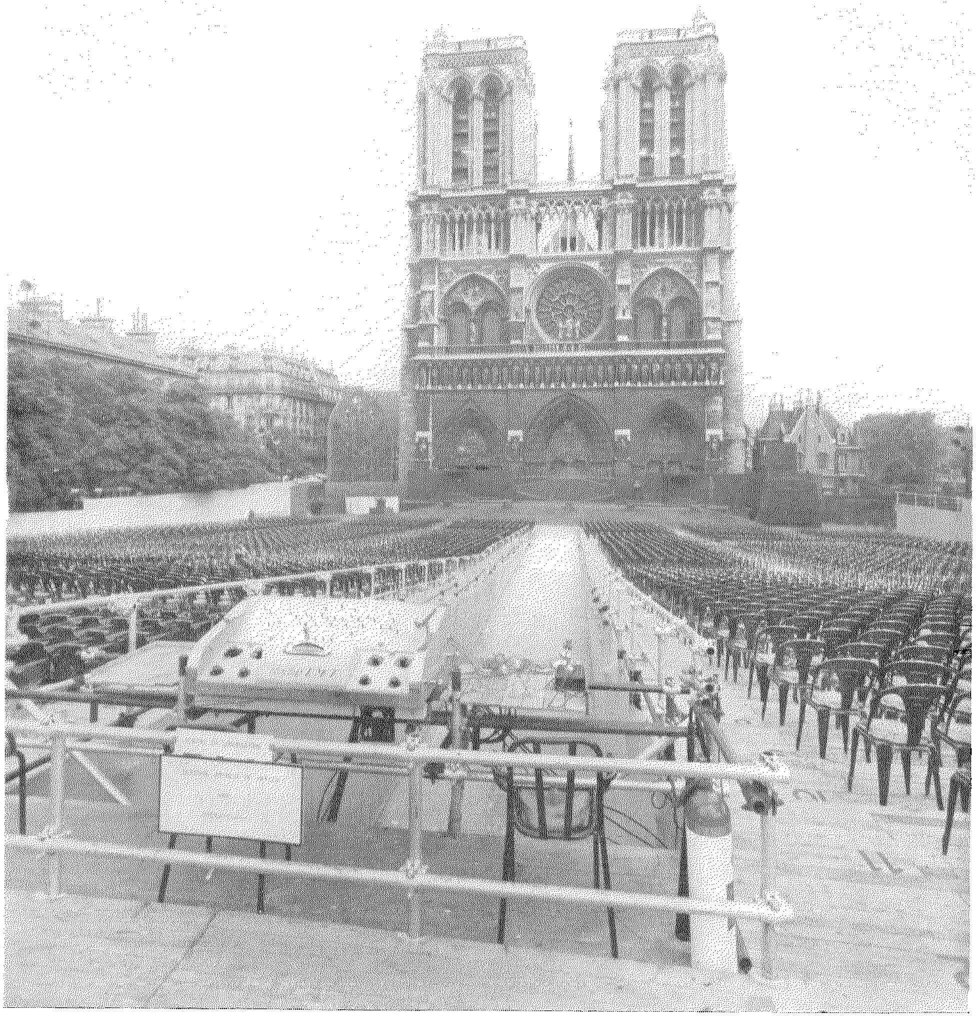
[1] From a technical point of view, mention may be made of the firm which built the seating accommodations: Société Entrepose de Paris, and the lighting contractor: Etablissements Jaccopozi of Paris.



Notre Dame Cathedral showing the Stage and about One-Half of the Auditorium. The Operating Switchboard is in the foreground and the Auditorium Loudspeakers are Visible at the Extreme Left.

either the portal of Notre Dame, or scenery representing the Calvary. No curtains or accessory paraphernalia facilitating the concealment of lighting fixtures or microphones were used.

The only visible projectors and loudspeakers were those placed on the right and left extremities of the auditorium. On the stage, five cases, hardly 40 cm. high, were placed at the top of the front slope opposite the audience. These boxes contained lighting projectors, microphones, and loudspeakers.

The Public Address System

The requirements for the public address system as a whole were:

(1) Retransmissions, throughout the entire square and auditorium, of the musical programmes performed within the Cathedral, such as choir renditions, organ solos, and other musical contributions (violins, cellos, and "Martenot" waves—etherodyne musical apparatus). These retransmissions, with variable power according to the scenes of the "Vray Mistère," had to be accomplished in a manner such as to give the audience the impression that the music was emanating directly from Notre Dame itself. It was, therefore, necessary to avoid having a single acoustic focus. In the last scene, the sound had to give the impression both of increasing power and of rising from the ground up to the top of the towers. Sufficient power was then required to cover the bells and chimes ringing a full peal, as well as the trumpets of the Republican Guards occupying the right and left of the stage.

(2) Amplification, over the entire area reserved for the public, of the actors' voices from any part of the stage or from the intervening space between the stage and the first rows of spectators' seats. In so far as practicable, it was necessary that the impression be conveyed that the sound was coming directly from an actor moving about the stage.

(3) Amplification of the voices of actors representing apparitions. In these cases, the movements of the actors were restricted and the microphones were placed as near to them as possible.

(4) Amplification and retransmission of the chimes of the Rouen Cathedral to Paris by telephone cable (140 km.). To avoid confusion with the bells of Notre Dame, this carillon emanated from loudspeakers placed on either side of the spectators rather than from the loudspeakers on the façade of Notre Dame.

(5) Placing at the disposal of the stage manager a telephone installation duplicated by transmitters connected with loudspeakers and lamp signals, so as to provide for a perfect coordination of all the elements, some of which were located far apart.

Main Difficulties of Realisation

The main difficulties involved were the following:

(*a*) To obtain a perfect retransmission of the musical part of the programme, with adequate pressure and the quality necessary to cover effectively the whole square, "Place du Parvis."

(*b*) To amplify, under the unfavourable conditions described above, the voices of the actors, apparitions, and chorus, with special reference to the solution of the problem of the "Larsen effect" (singing or reaction of loudspeakers on microphones).

Power and Quality for Musical Retransmissions

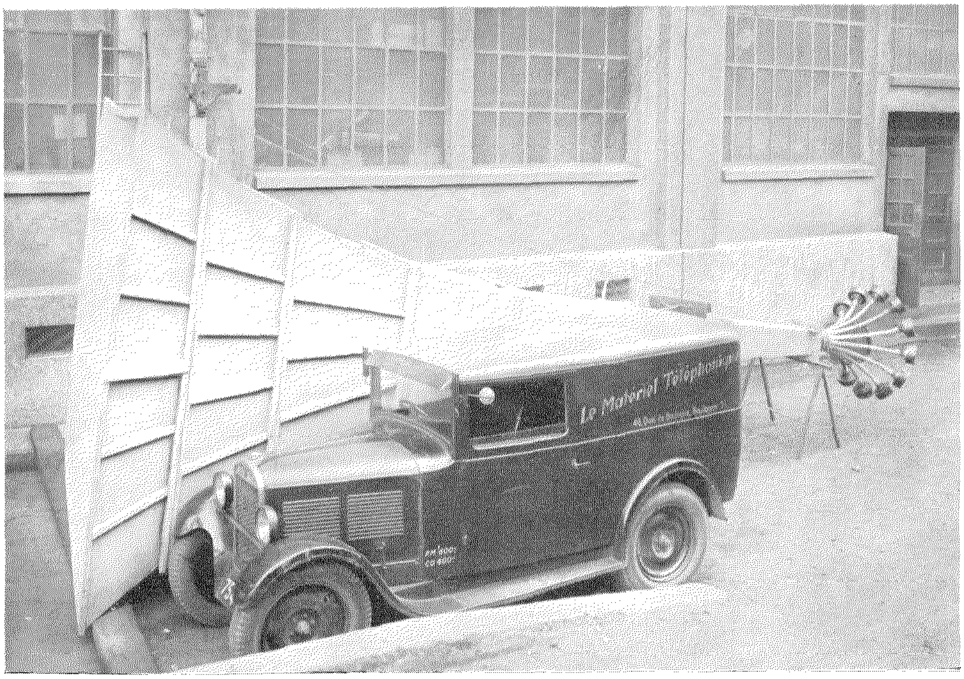
It was estimated that the average acoustic power of the Cathedral chimes at the center of the square would be from 6 to 10 Baries, and it was necessary to attain this value as a minimum. Taking the amplitude of acoustic pressure as p, and the acoustic resistance of the atmospheric air as r (equal to 42 c.g.s. units), the acoustic power flowing through a surface S cm.^{2} is

$$W=\frac{p^2}{2r}S.$$

Hence, in order to obtain a pressure of 10 r.m.s. Baries, that is an amplitude of $p=14$ Baries:

$$\begin{aligned} W&=\frac{196}{84}\times 8400\times 10^4\times 10^{-7}\text{ watts,}\\ &=19.6\text{ watts.}\end{aligned}$$

One can thus estimate the necessary acoustic power from 15 to 25 watts in the working angle of the loudspeaker. Such a loudspeaker, especially one possessing remarkable acoustic qualities, was not in current use; and, moreover, the usual solution of grouping several loudspeakers



Giant Loudspeaker.

in one place was not satisfactory because of the probable occurrence of stationary waves. The problem, in fact, was a delicate one, particularly as the apparatus on the façade of the Cathedral had to be practically invisible.

The "Larsen Effect" on Theatrical Retransmissions Including Apparitions

The amplification limit of a loudspeaking system is reached when the effects of the loudspeaker and the original sound on the microphone become equal. From this moment on, the sounds maintain themselves. Often the frequency first maintaining itself is not one that was originally present but rather, one that is most favoured by the whole installation: local conditions (frequency of resonance of the locality), the relative positions of the microphones and loudspeakers, and the presence of absorbing or reflecting screens. "Singing" is thus, in general, produced by a frequency different from the frequencies originally transmitted, and before the limit is reached for the latter. Before the "singing" phenomenon proper occurs, that is, at slightly lower amplification, resonance takes place through successive amplifications (with attendant attenuation in transmission) of the favoured frequency or of other frequencies registered by the microphones, the result being similar to the phenomenon of reverberation produced in a room with echo effects. In order to avoid these objectionable phenomena, the amplification coefficient must be kept appreciably below the "singing" point.

For sounds of given power there exists, therefore, even with microphones of high fidelity and stability, a distance beyond which it is impossible to obtain in the loudspeakers power sufficient to meet the requirements of a large assembly. This determines what is termed the "microphone field." When several microphones are connected simultaneously in the same installation, the respective field of each, in general, decreases; for, at certain frequencies, the combined action of the loudspeakers on the microphones is in phase and this augumented effect correspondingly lowers the amplification coefficient at which "singing" takes place. The advantage of multiple microphones is dependent upon their being connected-in properly at any given time, either one, two, or three, as required.

The problem is, therefore, one of switching, and may be considerably simplified by the judicious choice of suitable apparatus, particularly microphones and loudspeakers.

Material

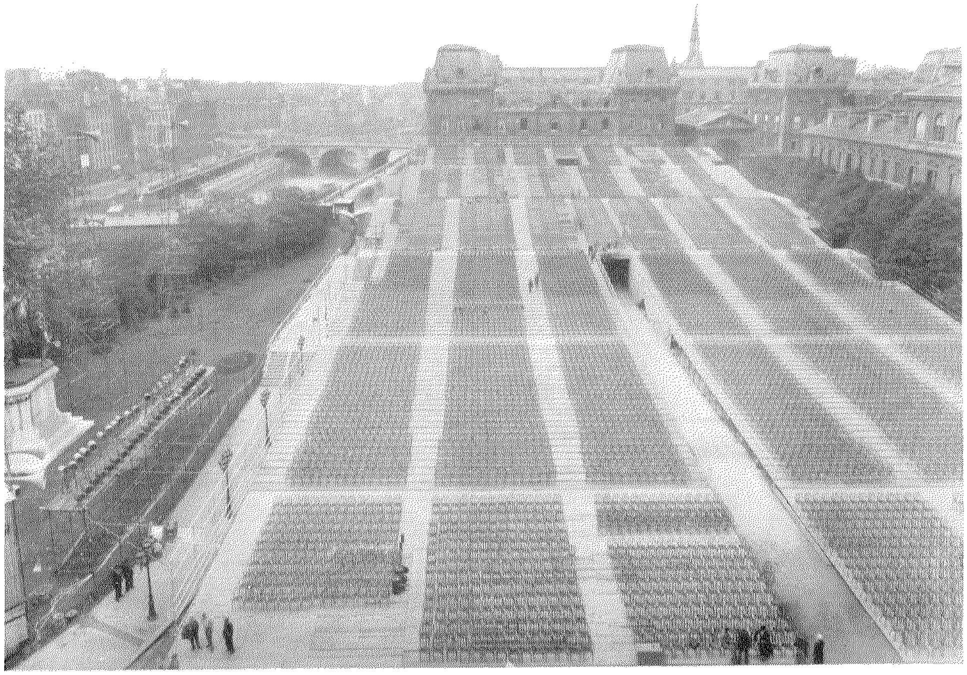
Loudspeakers

The electrodynamic type, with a small diaphragm, air chamber, and exponential horn was chosen because of its robust and water-tight construction, ease of installation, high efficiency, and, above all, its very pronounced directional qualities, permitting coverage of greater distances.

In order to simplify installation and reduce fire hazards, the model used for the "Vray Mistère" was of the permanent magnet type. The horns were 2 m. long and 80 cm. in diameter. Where there was insufficient room to locate these horns, they were replaced by flat flare horns 1.70 m. long, 1 m. wide, and 35 cm. thick, or by wooden horns of the compact type only 35 cm. in width.

Microphones

The electrodynamic type of microphone was chosen on account of its adaptability to operation in all positions, its insensitivity to mechanical vibration (thus requiring no elastic supports, and consequently facilitating installation and concealment in the scenery), its insensibility to hygrometric variations of the atmosphere, and its water-tightness (on several occasions these



Place du Parvis, showing the Auditorium as viewed from the Cathedral. The Prefecture de Police is in the background, and the Hotel-Dieu Hospital to the Right. The Auditorium Loudspeakers are Visible at the Left.

instruments operated in the rain), as well as its fidelity of reproduction, its low impedance (permitting the use of relatively long lines between the microphones and the amplifiers), and, finally and more important, the possibility of connecting several microphones on the same preamplifier without special precautions against reactive effects.

Two types were used: the "non-directional" type in places where the sound impinged from all directions; the "directional" type in other cases. Fifty microphones were used in the installation.

Amplifiers

Amplifiers with fairly flat frequency response were required in order to avoid "singing" on an enhanced frequency. In addition, it was considered necessary to secure high quality even at low speech levels. Class "A" amplifiers, ten in all, with 15 and 30 watts of acoustic power, therefore, were used. Because of the high power required, a class "B" type amplifier was used for musical retransmissions.

High quality preamplifiers—one per group of microphones—were also employed. The preamplifiers and amplifiers, fed by the town current supply, were grouped at one point, thus facilitating supervision and permitting quick adjustment if necessary.

Realisation of the Musical Retransmission

Microphones

Three microphones, two of the "directional" type mounted on pedestals 2.50 m. high, and one of the "non-directional" type suspended over the gallery of the great organ, were used with appropriate mixers to pick up the instrumental and choir music to be retransmitted. The placing of the artists with respect to the microphones was such that the resonance of the Cathedral was correctly apportioned in the retransmission.

Ordinary Loudspeakers

Four electrodynamic loudspeakers with flat horns were fitted in between the railings of the Gallery of the Virgin at a height of about 25 metres, and were distributed over the whole width of this gallery so as to ensure the required dispersion effect. They were fed by a 15-watt amplifier and covered the first third of the square.

Four similar loudspeakers were located on top of the towers. Operated by a 30 to 40 watt amplifier, they were intended to give the final sonorous ascent effect and were used only for this feature.

Special Loudspeaker

In order to obtain the requisite quality and power at the centre and rear of the square, a "giant" loudspeaker was especially constructed for the purpose. It employed twelve electrodynamic motors of the current type and a single straight exponential horn 6.80 m. in length with an aperture greater than 8 square metres.

This loudspeaker, possessing an efficiency estimated at 25% and giving a considerable directional effect, yielded the desired result. The peak of acoustic power at the amplifier outlet was 90 watts, the average being 40 to 50 watts. Moreover, the quality was greatly superior to that of current types of loudspeakers, especially at low frequencies.

The speaker was mounted on the platform between the two towers and behind the gallery joining them at their base at a height of approximately 50 metres.

Operation of the Installation

For broadcasting the theatrical performance with musical accompaniment the giant loudspeaker was nearly always employed alone in order to avoid interference with the actors' microphones. For retransmitting solos and music from the choirs and organ, during intervals of scenery changes, the loudspeakers in the Gallery of the Virgin were added at full power in order to give the first rows of spectators the impression of sufficient volume.

Because of the considerable directional effect of these loudspeakers, the sound coverage between these two groups of loudspeakers took place at a distance from the Cathedral such that no echo effects were noticeable. For the final scene, the ascension of the sound was obtained in the following manner: the loudspeakers in the Gallery of the Virgin were first worked alone at low volume; then, progressively, the loudspeakers in the towers were amplified while those in the Gallery were being diminished to zero. At last, the central loudspeaker was placed in operation with gradual increase in volume.

During the performance, claps of thunder were imitated on the organ and with the "Martenot waves." Since the volume was adequate, the impression given was most realistic.

Realisation of the Theatrical Retransmissions Including Apparitions

Central Operating Switchboard

Operation of the Microphones

In the successive switching of the microphones, precautions had to be taken to prevent difficulties due to distortion, power variation, switching noise, and clicks. Rapid and easy switching was required.

Finally, all the public address operations and their control had to be handled from a central point in the public auditorium. It was necessary for the control operator both to see and hear the actors in order to follow the action.

The main idea was to establish a switchboard from which switching of microphones could be effected through a single lever, capable of motion in two directions at right angles to each other. Each position of the lever corresponded to a given point on the stage, i.e., the connection of the microphone covering the amplifiers. For adequate microphone field coverage and to permit encircling an actor placed in the midst of four microphones, an intermediate position was arranged between each main position of the lever for the interconnection of two adjacent microphones.

On account of the distances involved, the microphone switching could not be accomplished directly from the switchboard. A relay box placed under the stage and functioning as a junction box between the microphones and the cables connecting them to the preamplifiers was therefore utilised.

A signal board equipped with lamps completed the switchboard unit and at any moment indicated to the operator the microphones in operation. It included an individual key per microphone enabling each microphone to be switched in or out separately. The latter arrangement proved especially useful in lengthy scenes when rapid interchanges occurred between widely separated actors and when the simultaneous operation of distant microphones was necessary.

Associated with the above mentioned operating lever was a cancellation key of the push type, permitting suppression of the previous setting. Lamps of suitable color indicated the combination effected. Preparation of a microphone set-up before actually switching it in was thus a simple matter.

A repeater signal board, indicating only the microphones actually connected, was provided for the stage manager.

The relay box controlling the microphones was designed so that each relay operated a microphone and a signal indicating its connection. The signaling device consisted of a pilot lamp, or of a more important visual "SILENCE" signal which functioned through relays and which was used in connection with the projector microphones to warn the operators of their operation. For special retransmission and other purposes, the signal was also used in connection with certain microphones located in the wings.

Power Control

Power control was effected from the relay box unit. Since it was, impracticable, for reasons of location, distance, and safety, to locate the preamplifiers within this unit, all adjustments were made through artificial lines connected between the preamplifiers and the power amplifiers. Independent adjustability of amplifiers and, in some cases, of loudspeakers was required for achieving the necessary flexibility and reliability. Power adjustments could be made prior to the operating periods.

In addition to individual operating keys in the control switchboard, the relays were arranged for operation by the general level of the microphones. Amplifiers and preamplifiers were thus added or suppressed as required, and perfect quietness of the installation was attained. Pilot lamps also indicated the potentiometers in service and facilitated control of the equipment.

Loudspeakers

The three groups of loudspeakers for the apparitions—Heaven, Hell, and the Gallery of the

Virgin—were placed as close to the point where an actor was speaking as was possible without danger of "singing." In most cases the actors, being motionless, supported the microphone themselves, and the loudspeakers—two per apparition—were at a distance of from 3 to 4 metres from the actor. The directional effect thereby obtained was perfect, provided other microphones were not operating simultaneously.

The loudspeakers transmitting the actors' voices from the stage were mounted on either side of the public auditorium: on the buildings of the Hotel-Dieu Hospital lining the square on the left, and on metal pillars 15 and 20 metres in height on the right. The whole surface of the auditorium was divided into six zones, each zone being simultaneously covered by two loudspeakers (or groups of loudspeakers) belonging, respectively, to the group on the right and on the left.

Analysis relative to the disposition of these highly directive loudspeakers showed that:

(1) In order to avoid echo effects, the difference in distance between the spectators of one zone and either the actors or the loudspeakers should not exceed 22 metres.
(2) The two loudspeakers covering any one zone should be at approximately equal distances from the centre of the stage.

This disposition of loudspeakers made it possible to give a more or less perfect illusion that the sound was coming from the centre of the stage. To approximate the binaural effect, the relative intensity of two groups of loudspeakers was varied.

While additional arrangements were made for the coverage of the front rows, spectators seated there were at some disadvantage as regards acoustic effect, as were also those in the lateral zones who were located too close to one or the other of a group of loudspeakers.

Complementary Installations

Complementary equipment was not installed on as elaborate a scale as the public address system, but its function was of no less importance, since it enabled the stage manager and his different collaborators to act quickly. This subsidiary equipment consisted mainly of ordinary telephones, loudspeakers for giving orders, and light signals.

Telephones

A central battery manual telephone switchboard provided facilities for interconnection to the stage manager, the electricians, the public address operating switchboard, the main points of the performance, the organ gallery, the control points of the loudspeakers (galleries, platforms, and towers), and the distant apparitions, totaling approximately 20 points. A special telephone line was reserved for coordinating the chimes from Rouen. A skilled telephone operator was in charge of the switchboard.

Paging by Loudspeakers

A microphone was at the disposal of the stage manager, who by means of a keyboard could communicate instantly with the electricians, the organ gallery, or the public address operating switchboard. At the latter point, instructions were not given through loudspeakers, which would have disturbed the audience, but through head phones to a second operator assisting the first one. These head phones were subsequently left in permanent connection with the microphone of the stage manager so as to be in closer touch with him and to repeat the orders passed to other posts.

Special precautions were taken to prevent the stage manager from using the loudspeaker at the organ by mistake while the adjacent microphones were working. Such use would have resulted in the retransmission of the orders throughout the square. When these microphones were connected, an imperative warning was given to the stage manager by a pilot lamp near the operating key of the loudspeaker; moreover, a relay then prevented the use of this loudspeaker. An additional operation allowed the stage manager himself, in case of necessity, to cut off the microphones of the organ to convey an urgent order.

Signaling

Certain starting signals, especially for musical renditions, were given by a pilot lamp. Similar indications as to procedure also were used in connection with certain actors and their associated microphones.

Recent Telecommunication Developments of Interest

Coin Checking Device for Automatic Coin Slot Machines. The constantly increasing application in public places of distribution machines for the purpose of facilitating the sale of commodities, railway tickets, and postage stamps, as well as in connection with in- and outdoor telephone service, emphasises the problem of finding means for preventing the dishonest use of such devices. To meet this need, the Bell Telephone Manufacturing Company, Antwerp, recently developed a coin checking mechanism which prevents refunding of coins through tampering and which, in addition, discriminates automatically between genuine and fraudulent coins.

The device may be adapted to any machine used for the dispensing of commodities or services. As developed to date by the Bell Telephone Manufacturing Company, it is comprised in a public pay station system for single coins (local full automatic) and multiple coins (suburban and interurban automatic).

Discrimination between genuine and fraudulent coins takes place in two ways: (1) dimensional checking, a method commonly used, but which must not be too close in view of the rather wide variations occurring in genuine coins; and (2) magnetic permeability checking.

Machines to be used in Belgium will take three coins, namely, 25 centimes (U.S.A. value 0.85 cents), 1 franc, and 5 francs. Because of the small value of the first mentioned coin, it was not thought worth while to guard against its fraudulent use other than by a check of dimensions. The two larger coins are composed of nickel alloy having a magnetic permeability intermediate between iron and non-magnetic material. Since fraudulent coins are most likely to be made of cheap material such as iron, brass, or zinc alloy, the machine is designed to pass only coins of suitable permeability.

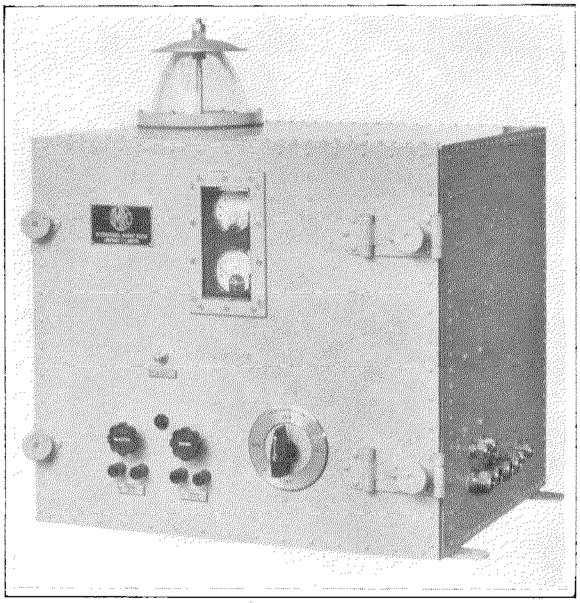
For the separation of nickel alloy coins from iron and non-magnetic counterfeits, a magnetic scheme is utilised. Non-magnetic coins, of course, are not attracted to the magnet poles, while iron coins are firmly attracted. Nickel alloy coins on the other hand can be readily disengaged by a suitable force. Since the magnetic permeability of iron, compared to the Belgian nickel alloy coins, is in the ratio of five to one, ample margins of safety are readily obtainable.

In designing the new mechanism, discrimination between genuine and fraudulent coins by weight was discarded. Genuine coins, because of variations in dimensions due to wear, vary rather widely in weight; and furthermore, discrimination of weight would require an accurate automatic scale. In addition, coins of cheap material but of equal weight could be used so that an automatic scale in any case would be of little use.

It is expected that the new pay station system will be placed in service in Belgium shortly. Details of this system, including the coin checking device, will be published in a later issue of *Electrical Communication.*

* * *

Lifeboat Equipment on the R.M.S. Queen Mary. Two of the twenty-four motor lifeboats carried by the *R.M.S. Queen Mary* have been equipped with special radio communication and searchlight equipment developed by the International Marine Radio Company Limited, London, the supplier of the entire radio installa-



Transmitter and Receiver in Submergible Unit.

tion for the *Queen Mary*. In addition to the spark transmitting and receiving set required by law, a special radio telephone installation is carried by each of the two lifeboats, the *Queen Mary* being the first ship to be thus equipped.

The functions of the two radio-equipped lifeboats, in case of emergency, are to act as controlling agents for the rest of the boats, to shepherd them, and to maintain contact with rescue ships, with one another and, if necessary, with the parent ship.

The Type TG4 spark transmitter and receiver are combined in a single submergible unit which also houses auxiliary and testing gear. A battery-driven motor-generator, Morse key, headphones, etc., complete this section of the installation.

The quenched spark transmitter consumes 300 watts from the alternator, delivering an output well in excess of the Board of Trade requirement of 10 meter-amperes on the marine distress wavelength of 600 meters. The receiver is a 3-valve regenerative type. The accompanying illustration shows the simplified controls and conveys some idea of the rugged construction required for this type of service.

The telephone transmitter and receiver are separate units, comprising a standard trawler type equipment. The transmitter (Type TS3) operates from a small battery-driven motor generator, and covers the "small ship" telephony waveband of 110 to 220 meters. The receiver (Type RM14) covers the band of 110 to 2,000 meters.

Both the telegraph and telephone sets derive their power supply from a common 22-volt nickel-iron battery and employ the same aerial, which is of the single wire type supported by collapsible masts. The operating range of both sets is well over 100 miles.

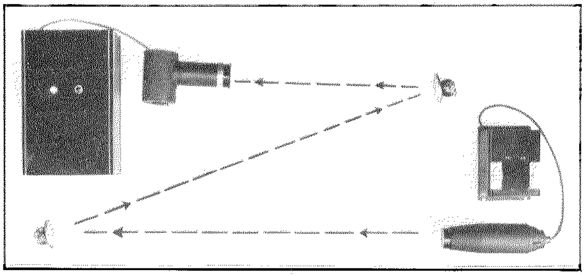
The searchlight, mounted on top of the radio cabin, also operates from the same battery and has an illumination range of some 700 yards.

* * *

INFRA-RED BURGLAR ALARM. An interesting application of infra-red rays and photo-cells for burglar alarm and similar services has been developed by the Bell Telephone Manufacturing Company, Antwerp, Belgium. The equipment consists essentially of a projector of invisible infra-red "light," a photoelectric cell responsive to infra-red rays only, and an amplifying system following the photo-cell. One or more mirrors permit the path of the infra-red beam to be deflected around corners or zigzagged across the area to be protected.

For burglar alarm use, the mains-operated amplifier is connected to an alarm signal circuit so that a momentary interruption of the infra-red light beam will sound an alarm continuously. Since the alarm circuit is battery operated, failure of the mains or the apparatus, whether deliberate or accidental, will cause the alarm to function.

The accompanying illustration shows the essential elements—the infra-red projector, mirrors, photo-cell, and amplifier.



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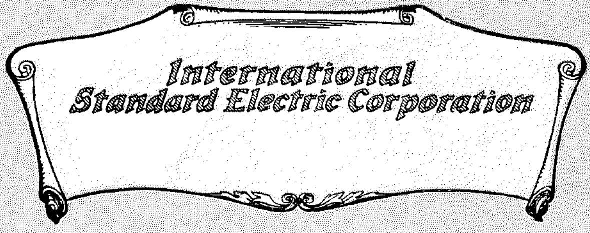
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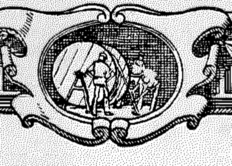

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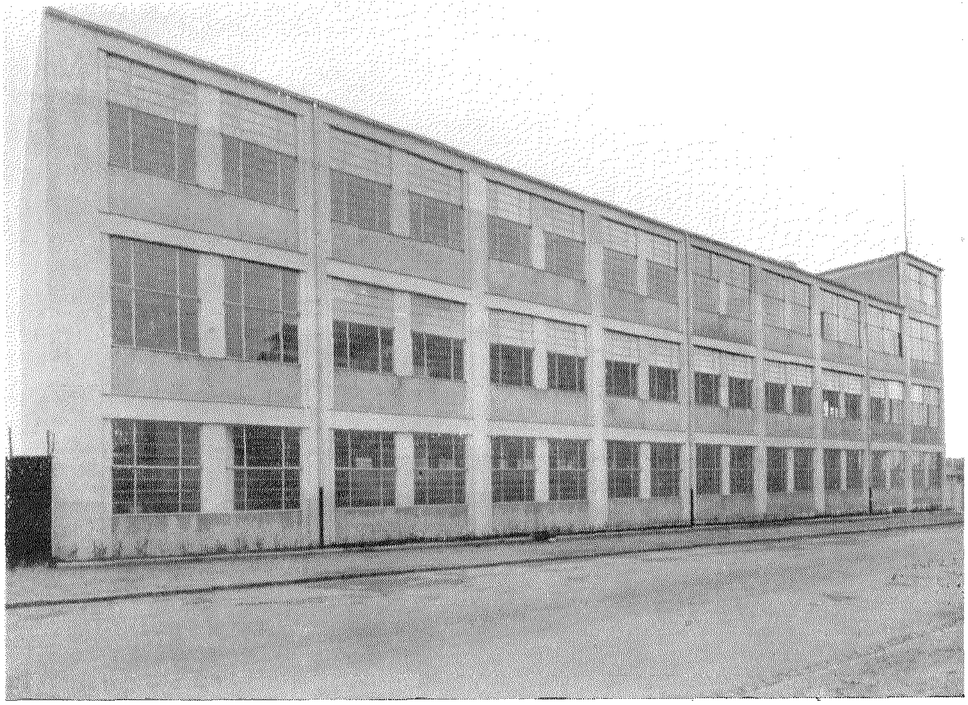

MODERN PLANT OF STANDARD ELECTRIC AKTIESELSKAB, COPENHAGEN, DENMARK, WITH FLOOR SPACE OF 2,860 SQUARE METRES (30,785 SQUARE FEET). CONSTRUCTED IN 1936 PRINCIPALLY FOR THE MANUFACTURE AND ASSEMBLY OF COMMUNICATION EQUIPMENT.

Automatic Ticketing of Telephone Toll Calls

By LESLIE B. HAIGH, M.A., A.M.I.E.E.,

Development Laboratories, Bell Telephone Manufacturing Company, Antwerp, Belgium

A NEW telephone facility known as Automatic Toll Ticketing, the first of its kind anywhere, was placed in public service on December 7, 1936, in the town of Bruges, Belgium. This event, which may have far reaching consequences, marks a further step forward in the evolution of communication systems. It demonstrates the practical possibility of offering to a telephone subscriber the advantages of full automatic dial service for toll as well as local calls, coupled with an individual printed record of every toll call, in which no human agency, save the calling and called parties, has been involved.

The Laboratories of the Bell Telephone Manufacturing Company, Antwerp, have been engaged for some time in studying the problems of introducing national dialing—"automatic toll" service—in several European countries, including Belgium, where the most important towns — Brussels, Antwerp, Liége, Ghent, Charleroi, Tournai, Bruges—and many of the small towns and villages surrounding them, already enjoy automatic service for urban and rural calls. In Belgium, many of the signaling and transmission problems involved in long distance dialing have already been solved by the extensive introduction of operator dialing over toll lines with the aid of the 50-cycle and "two voice frequency" impulsing systems. The second method has been described in a recent article.* One of the difficulties in extending toll dialing in Belgium to the subscribers themselves arises from the prevailing tariff law. Whereas a subscriber is charged for every toll call he makes, he is entitled upon payment of his annual rental to a limited number of local calls without extra charge. To comply with the law, the charges for toll and local calls must be computed separately. It follows that, if toll calls are to be metered automatically, each subscriber must be provided with a second message register for this purpose, a task of some complexity in existing automatic exchanges. Automatic ticketing also offers a solution to this problem.

A Field Trial Installation

The Belgian Régie has followed with interest the steps in the development since the idea of automatic ticketing was first mooted, and has assisted materially by giving the Bell Telephone Manufacturing Company the opportunity to tender upon several practical applications. Acknowledgment is due also to the engineers of The Hague Municipal Telephone Administration for the sympathetic interest they have shown in the discussions which have taken place on this subject.

On April 22, 1936, the Régie placed with this Company an order for a field trial installation of automatic ticketing equipment in the Bruges exchange. This equipment was to permit calls to be established by dialing and without the intervention of an operator, from Bruges subscribers to subscribers in the neighbouring seaside town of Blankenberghe, nine miles away, and therefore outside the local zone.

Both towns have had dial service for local calls for some years. Bruges is the toll switching centre of West Flanders, and the 3000-line automatic exchange, cut-over in October, 1932, was one of the first 7-D Rotary System installations in Belgium (Fig. 1). Blankenberghe has a 900-line exchange, also 7-D Rotary, dating from July, 1934, and it was designed at the outset for direct dialing in the direction Blankenberghe-Bruges on a multi-metering basis. Traffic in the opposite direction has hitherto been handled manually, the operators in Bruges dialing the numbers of the Blankenberghe subscribers, and supervising and ticketing the calls.

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* " The Application of Voice Frequency Signaling to C.L.R. Service in Belgium," by G. E. H. Mönnig, *Electrical Communication*, October, 1935.

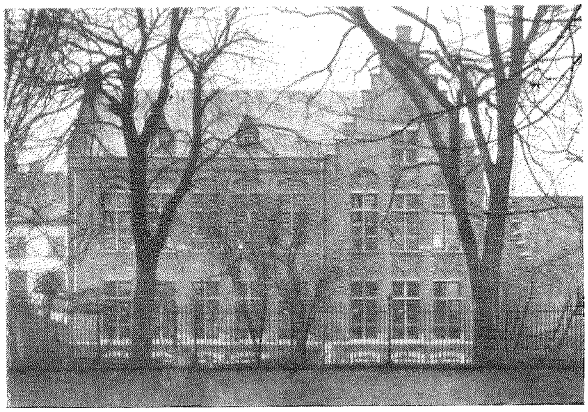


Fig. 1—The Telephone Exchange, Bruges.

Requirements of a System of Automatic Ticketing

In any system of automatic ticketing of telephone calls, the absolute minimum of information recorded upon each ticket must be such as to determine directly or indirectly the proper charge for the call and the identity of the subscriber to whom it is chargeable. The latter can evidently be conveniently indicated by his directory number. The charge can be computed in a variety of ways: directly by automatic means and recorded by a code or in monetary values; or indirectly from a record of the directory numbers of the calling and called subscribers (or of the unit tariff), together with the duration of the call (or the time of commencement and termination).

In the installation in question, a record is made upon each ticket of more particulars than are strictly necessary and the ticket is thus both adequate for accounting purposes and acceptable to the subscriber. The record consists of the directory numbers of the two subscribers, the tariff per time-unit of conversation, and the number of such units expended. The date and the time of day (to the nearest 5 minutes) are also recorded for the benefit and satisfaction of the subscriber, together with identification marks useful to the operating staff.

Comparison of Present and Previous Routing

It is interesting to compare the routing of calls since automatic ticketing was introduced with the method by which the same calls were established previously by operators, and thereafter to examine the problems involved in obtaining automatically the information which those operators themselves recorded upon the tickets.

Before the introduction of automatic ticketing, a Bruges subscriber desiring a connection to a Blankenberghe subscriber first dialed special service "02." The Bruges register routed the call over first and second group selectors (see A, Fig. 2) to a jack circuit at one of the rural positions. An operator inserted a plug in the jack and enquired both the number of the caller and the number desired. She then inserted the second plug of the same cord in the calling subscriber's multiple jack. Having verified the correctness of the information given, she released the original dialed connection by a key and transferred the first plug into the jack of a line to Blankenberghe. Another Bruges register attached itself to this line and the operator dialed into it the five digits of the desired number. The register routed the call to the line of the Blankenberghe subscriber and, whilst awaiting his reply, the operator prepared a ticket for record. At the end of the call the ticket was completed and despatched, together with other toll tickets, to the sorting table.

The new service has simplified the procedure whilst involving a minimum of modification of the existing plant. The lines to Blankenberghe, hitherto accessible only to operators, now appear in the arcs of the first group selectors and are each furnished with a printing register and a controlling relay group or "outgoing repeater" containing timing apparatus (see B, Fig. 2). A Bruges subscriber dials, instead of "02," the number of the subscriber he desires to call. The routing register selects a line to Blankenberghe over the first group selector and then routes the call directly to the desired line in that town. A printing register, associated with the outgoing end of the toll line, is supplied automatically with the necessary information for the recording of the call. When the call is finished, the register produces a ticket with the information printed upon it and ejects it through a chute into a container.

Printing the Number of the Called Subscriber

Although the Blankenberghe exchange as yet has less than one thousand subscribers, it is in the Bruges rural area in which all subscribers have five digit directory numbers. It follows that all the Blankenberghe subscribers have numbers beginning with the same two digits, which the routing register recognises as indicating a Blankenberghe call and translates into the single train of impulses required for the selection at the first group selector. The remaining three digits are transmitted without translation to the outgoing relay group, which relays the impulses both to Blankenberghe and to the digit-wheel in the printing register. The latter thus receives the last three digits and prints them upon a paper strip as they arrive, but receives no indication of the first two digits. However, these digits are always the same, as already stated, and the printing register is furnished with a patented device whereby at the first printing operation they are printed in front of the digit received. The strip now carries a record of the called subscriber's number.

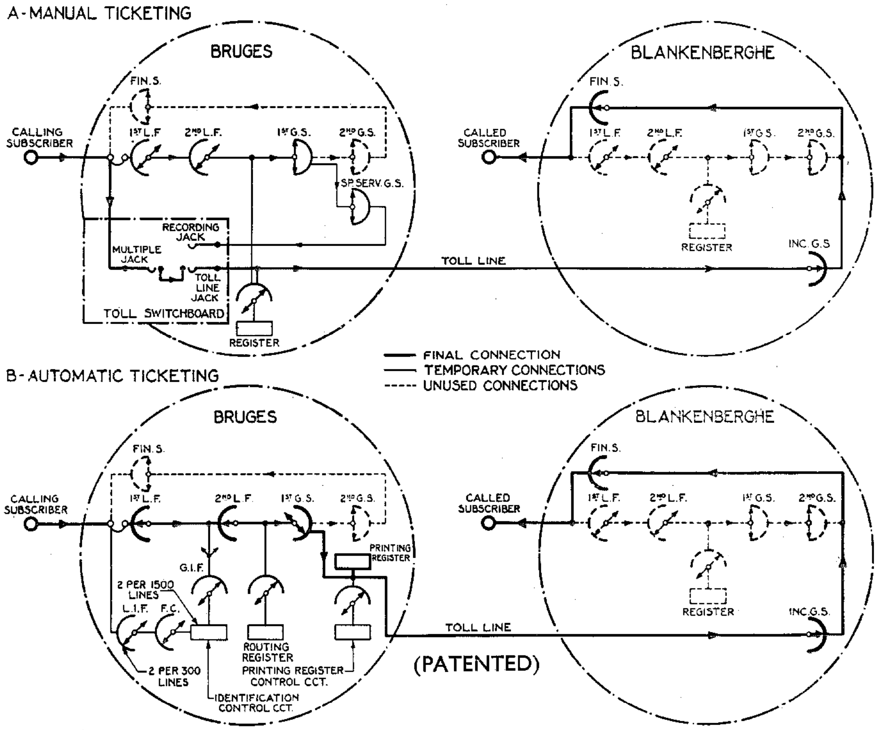


Fig. 2—Routing of Calls from Bruges to Blankenberghe, Before and After the Introduction of Automatic Ticketing.

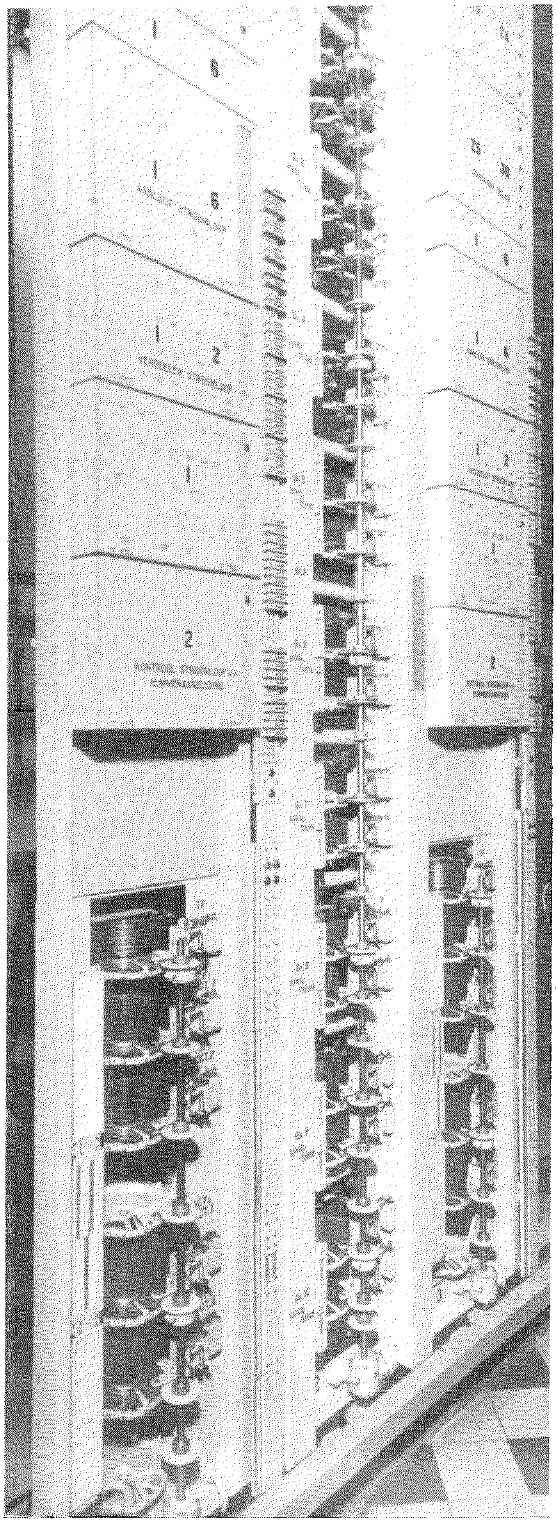


Fig. 3—The Calling Line Identification Equipment.

Printing the Charge per Time-Unit of Conversation

As soon as the selection of the desired line is complete, the routing register disconnects itself, and from this moment two series of operations take place simultaneously. On the one hand, upon the reply of the called subscriber, timing of the call begins in the outgoing relay group and, after the usual six seconds of "free time" have been counted, the call is registered as "effective" and chargeable by the operation of a relay. On the other hand, one of a common group of "printing register control circuits" attaches itself over a finder switch to the outgoing relay group and proceeds to direct the printing of the "tariff" or charge per time-unit of conversation. In the present installation, since only calls outgoing from Bruges to Blankenberghe are as yet ticketed automatically, this operation is quite simple, for the tariff is always Frs. 0.80. The printing register is capable of printing any number composed of four digits and can also print a "dash" when required. The control circuit accordingly creates the requisite trains of impulses and transmits them to the digit-wheel in the printing register for printing at the end of each train of impulses. In order to separate francs and centimes by a "dash," the printing signal is given to the register without any impulses to the digit-wheel, and the strip now carries also the inscription 0-80.

Printing the Number of the Calling Subscriber

The next operation presents greater difficulty. It is necessary, in the first place, to determine the identity of the calling line, which can be achieved only by tracing the call back to the line equipment; and, in the second place, to convey this information from the line equipment to the printing register. Since these two points in the connection are separated by first and second line finders and first group selectors, which were already existing, the provision of a new signaling path by the addition of brushes to these switches was evidently impracticable. The use of alternating currents at voice frequency made an economical solution possible, involving a very small amount of modification and disturbance to existing equipment. In each "link circuit" a condenser is connected between one of the brushes of the first group selector and the "metering" brush of the second line finder. A lead is run from the metering brush of each first line finder through a condenser to new and patented equipment known as the "Calling Line Identification" equipment. Finally, a connection is made from every subscriber's message register to this equipment.

To initiate the identification process, the printing register control circuit connects a 2,000-cycle tone to a lead in the outgoing relay group, whence it passes through the link into the identification equipment. Here it is detected in a starting circuit containing a thermionic valve; and a group identifying finder in one of a group of "identification control" circuits, which has been preselected by an allotter, begins to rotate. This finder has a terminal in its arc reserved for each group of first line finders, and to this terminal are connected the leads coming from the metering brushes of all the first line finders in that group. The calling tone thus finds its way to one of these terminals, and as soon as the rotating finder reaches this terminal, the tone is detected a second time by another thermionic valve and the rotation is arrested. The position in which the finder has stopped now indicates the group of first line finders which has access to the calling line. In Bruges, although jumpering facilities between the first line finder and final selector multiples are provided, all lines are jumpered "straight," that is, they appear in corresponding positions on the line finder and final selector arcs. It follows that, when the group of first line finders having access to a line is known, all the digits of that line's number except the last two are equally known. The first step in the identification of the calling line is thus achieved.

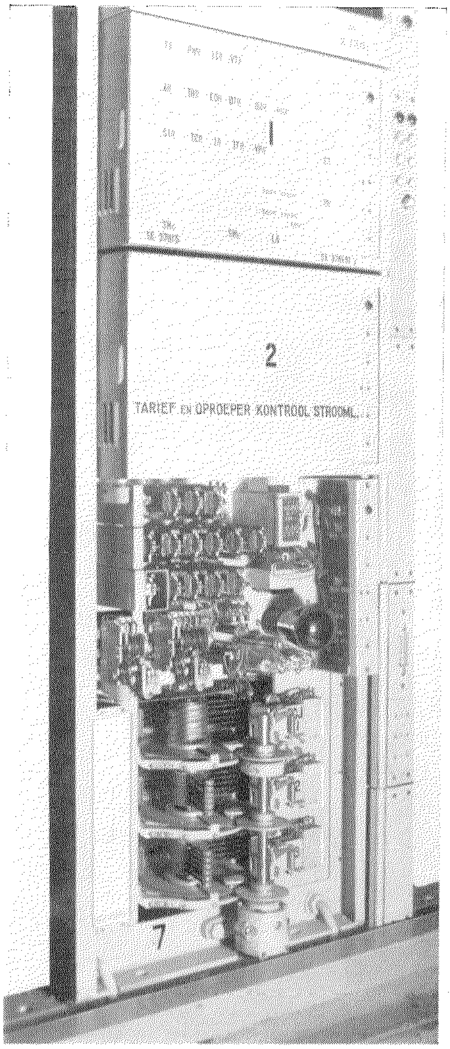


Fig. 4—The Printing Register Control Equipment.

The next step is to determine the position in which the brushes of the first line finder are standing, since this fixes the "tens" and "units" digits of the line number. To this end several groups of line identifying finders are provided. To the arcs of these finders the leads coming from the subscribers' metering wires are connected, one hundred lines to a level. There are three such levels on each finder, which therefore has access to 300 lines. The calling tone thus finds its way also to an arc terminal of each of the finders in one of the groups, the group being already known from the position of the group identifying finder. A finder in this group is accordingly chosen by the identification control circuit, through its finder chooser, and begins to rotate. When the brush reaches the terminal carrying the tone, the valve in the control circuit immediately detects it and the rotation is arrested. The position of the brushes indicates the last two digits of the line number, which has now been completely identified. As soon as this occurs a tone of a different frequency is transmitted in a forward direction from the identification control circuit, to the printing register control circuit, over the same path in which the calling tone is still being propagated in the opposite direction. It is detected by a valve and causes the calling tone to be disconnected.

The final step is to transfer the number of the calling line to the printing register. This is achieved by transmitting, again over the same path and to the same valve, trains of impulses of alternating current at tone frequency, controlled digit by digit in accordance with the positions assumed by the group and line identification finders. The impulses are relayed to the printing register and the digits printed one after the other upon the paper strip. The strip now carries a record of the directory numbers of the lines in communication and of the tariff chargeable, and the printing register is ready to record indications of the duration of the conversation.

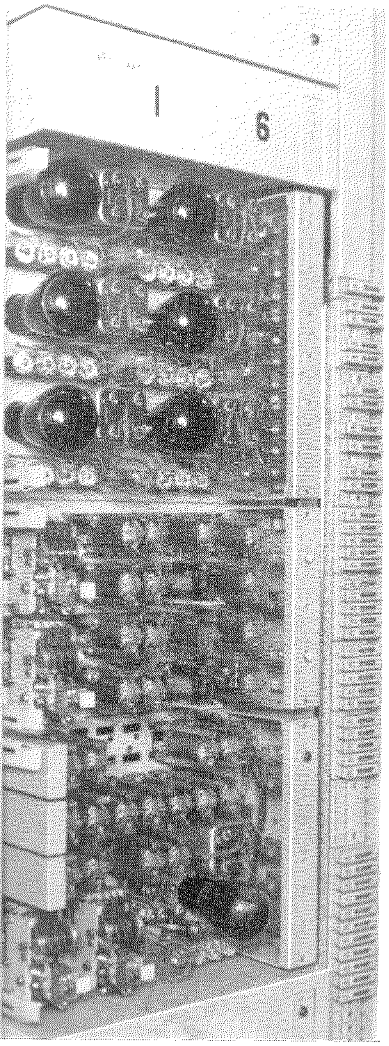


Fig. 5—The Layout of the Relays and Valves.

Recording the Duration of Conversation

By this time, an average of perhaps 15 seconds after the end of selection and the beginning of ringing, conversation may already have begun. If, or when, the call is registered as "effective," a signal is sent to the printing register and three small holes are punched one after the other in the paper strip. The time-unit of conversation in Belgium is normally three minutes; long-distance toll calls are, however, charged per elapsed minute after the first period of three minutes. For the sake of uniformity, the printing register has been designed to punch three holes, each representing a chargeable minute, upon receipt of the first signal and thereafter to punch one hole for each succeeding signal at one minute intervals.

The timing mechanism in the outgoing relay group consists of a step-by-step switch advanced under the control of a master chronometer. It sends signals to the printing register when the call is "effective," as already stated, and at the end of every minute thereafter, except the first two, when signals are unnecessary because three holes have already been punched. During the punching of these first three holes, the opportunity is taken to print the date, the time of day, and the machine's own identification mark and serial number. The three printing operations are spread over the three punching operations to reduce the load on the moving parts. Whilst conversation is in progress, the paper strip thus acquires further records indicating when conversation began and how long it lasted, together with useful identification marks.

Completing the Ticket

When the outgoing relay group receives the signal to release, the printing register advances the paper strip, if this be necessary, until sufficient paper to make a ticket of normal length has passed the knife. It then severs the strip and ejects the ticket into a chute.

The Identification Equipment

Theoretically, the relay and valve equipment composing the identification starting circuit could be common to the whole exchange; and a single group of identification control circuits would suffice. In order to increase the security of the new service in this trial installation and

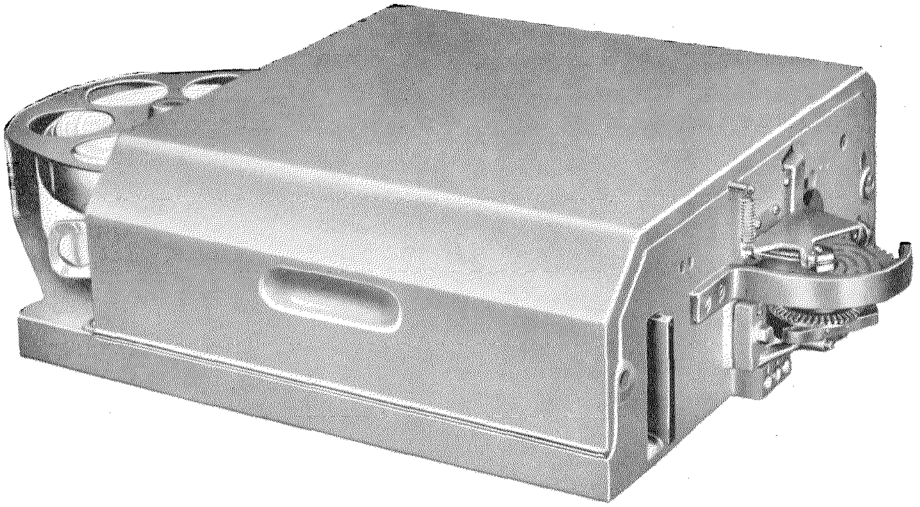


Fig. 6—*The Printing Register with Cover in Position.*

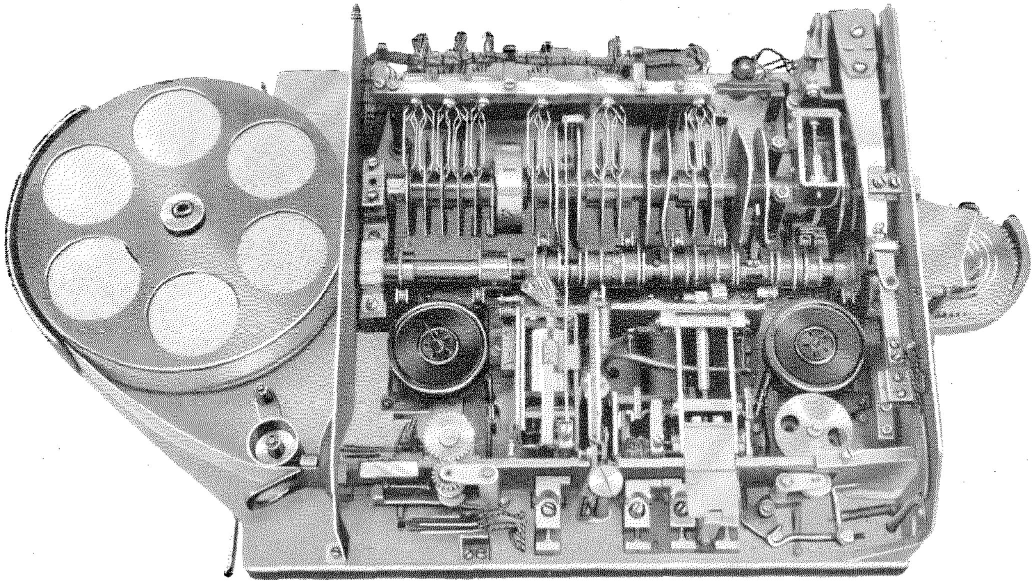
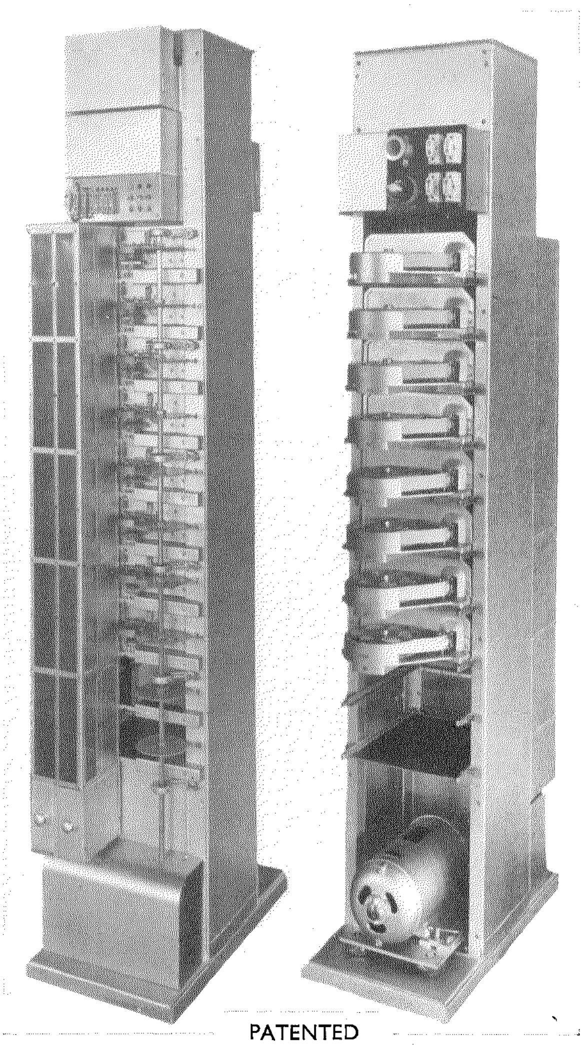


Fig. 7—*The Printing Register with Cover Removed.*

PATENTED

to avoid any possibility of unforeseen trouble throwing the whole identification equipment out of action, it was deemed advisable to provide a starting circuit for each 300 lines and a group of identification control circuits for each 1,500 lines. Two circuits in each group could easily carry the traffic expected from these lines but, also for reasons of security, space was reserved for a third. A group of identification finders was provided for each 300 lines, two finders being equipped with space reserved for a third. The whole of this equipment is accommodated upon three bays (Fig. 3). The centre bay mounts 30 identification finders and it will be seen that every third space is vacant. The other two bays are of the "combined" type, mounting the finders of the identification control circuits at the bottom, and the relay and valve equipment of these circuits and of the starting circuits above. The top finder on each combined bay is a routine test access finder. The bay is thus a complete unit serving 1,500 lines. (Fig. 5 shows the layout of the relay and valve equipment.)



Figs. 8 and 9—Front and Rear Views of the Printing Register Bay.

The printing register control circuits, inasmuch as they contain the valve and relay equipment for converting voice frequency signals into direct current signals, may be considered as accessory to the identification equipment proper. They are mounted on another "combined" bay together with the outgoing relay groups. The bay mounts ten relay groups at the top and three control circuits with their finders at the bottom; Fig. 4 illustrates the lower part of the bay. Figs. 3 and 4 together give an idea of the small amount of rack-mounted equipment added to a 3,000-line exchange, purely for purposes associated with automatic ticketing.

The Printing Register and Its Bay

Figs. 6 and 7 illustrate the power-driven printing register, and Figs. 8 and 9 show front and rear views of a patented apparatus bay designed to mount ten such printing registers together with suitable motor control and supervisory equipment.

The register measures 532 by 300 by 118 mm. (21 by 12 by $4\frac{3}{4}$ in.) overall, and is designed to jack-in from the rear of the bay. With the machine properly jacked-in, a flexible gear wheel protruding from the front (see Fig. 7) can be brought into engagement with the rotating vertical shaft of the bay. Through bevel gearing, the flexible wheel drives a shaft carrying mechanical cams. The different printing operations and the punching, cutting, and ejecting operations are controlled by these cams, which are engaged with the shaft in the proper sequence by mechanical means.

A strip of paper is fed from a roll into the rear of the machine, where it is caught between friction rollers, and passes between guides before various type wheels, a punch, and a knife; and the cut tickets are ejected through a deflector-slot into one of two chutes running

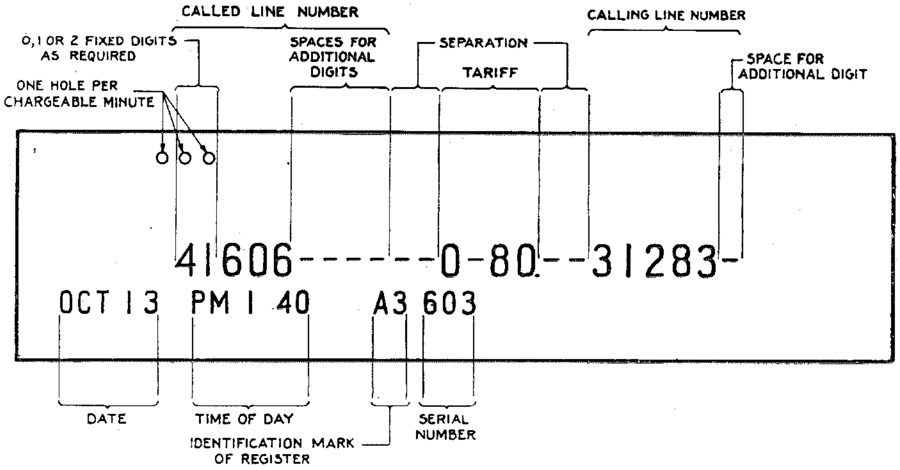

CALLED LINE NUMBER
0,1 OR 2 FIXED DIGITS AS REQUIRED
ONE HOLE PER CHARGEABLE MINUTE
SPACES FOR ADDITIONAL DIGITS
SEPARATION
TARIFF
CALLING LINE NUMBER
SPACE FOR ADDITIONAL DIGIT
41606------0-80--31283-
OCT 13 PM 1 40 A3 603
DATE
TIME OF DAY
IDENTIFICATION MARK OF REGISTER
SERIAL NUMBER

Fig. 10—*Illustrating the Arrangement of the Ticket.*

down the front of the bay. At the foot of each chute is a container, one for tickets of all kinds recording subscriber calls, and the other for routine test tickets which are separated automatically from the rest by the hinged deflector-slot. The bay is so designed that at a later date, when the traffic has increased sufficiently, the first container can be removed and the tickets conveyed by a belt conveyor direct to the sorting desk.

For each operation the cam shaft makes one revolution and the paper strip is advanced one step. The register has a normal cycle of 36 operations; the normal ticket thus has a length equivalent to 36 steps. The first 21 operations are concerned with the printing of the called and calling parties' directory numbers and the tariff with suitable spacing between them. The next 14 are punching or spacing operations, according to the duration of conversation; and the last is the cutting and ejecting operation. Calls lasting 14 minutes or less are thus recorded on a ticket 36 steps long. For calls lasting longer than 14 minutes, the ticket is extended without limit beyond its normal length. The date and the time of day are printed from type-wheels advanced by impulses transmitted by a master clock. The fixed type, from which are printed the register's own identification mark and the invariable digits prefixed to the called line number, are carried on members arranged to jack-in and are therefore readily changeable. The other numbers are printed digit-by-digit from a type-wheel advanced by current impulses from the associated relay group and restored mechanically after each printing operation. A standard typewriter ribbon supplies the ink for printing and is advanced and reversed automatically.

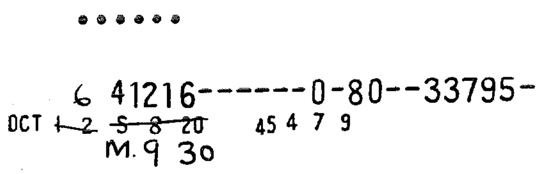
The Ticket

Fig. 10 is a full size illustration of a typical ticket of normal length. It measures 116 mm. by 30 mm. ($4\frac{5}{8}$ in. by $1\frac{1}{8}$ in.). It will be seen that, although each of the line numbers shown has five digits, the printing register is capable of printing calling line numbers with up to six digits and called line numbers consisting of up to seven variable digits preceded by one or two invariable digits. The discrepancy between the two numbers is explained by the necessity, in the case of long distance calls, of indicating the identity of the area or town to which the called number belongs.

The New System Proves Its Worth in Advance of Cut-Over

The first ticket recording a commercial call bears the date October 6. How it came to be produced two months before cut-over is a story in itself, and illustrates the immense value of the documentary evidence afforded by such a record. Fig. 11 is reproduced from a photograph of this interesting ticket.

On the day in question, testing of the equipment was in progress in preparation for a demonstration arranged for October 8. Amongst the test tickets in the container, a ticket was noticed which carried two regular subscribers' numbers. The calling number was found upon investigation to belong to a railway depot in Bruges. This number was immediately called up by the Administration and the official who replied was informed that a call had been put through automatically to Blankenberghe railway station. This was, of course, contrary to regulations because the new service was not yet open to the public. The call was at first emphatically denied, as might have been expected, since only the person in charge of the depot is allowed to make calls outside the Bruges local area. Eventually, when the overwhelming evidence of the date, time, numbers involved, and duration of conversation was appreciated, the call was reluctantly admitted by an employee—and duly charged.



6 41216------0-80--33795-

OCT ~~1 2 5 8 20~~ 45 4 7 9

M.9 30

Fig. 11—Record of the First Call Ticketed Automatically.

The Perpetual Clock Circuit (Patented)

An interesting innovation in the new equipment is the arrangement for adjusting automatically the type-wheels in the printing registers from which the date is printed. Precisely at midnight every day an impulse must be sent to all the date counters to advance the day of the month. At the end of the month two difficulties arise. In the first place, any counter constructed with tens and units digit wheels must necessarily have a cycle which is a multiple of ten steps. Actually the date counters have a cycle of fifty steps. At the end of each month, therefore, when a new cycle begins, the counters must be advanced. Secondly, the number of steps varies from month to month, as the number of days in the month varies. A special arrangement for dealing automatically with this situation has been devised. A small relay group and four step-by-step switches receive an impulse at midnight every day, and the switches are advanced according to a combination which is such that their relative positions are repeated only once in four years. The days of each month are counted and the appropriate number of impulses are transmitted to all the printing registers at the end of the month. During this process of adjusting the monthly cycles, the printing registers are prevented from recording non-existent dates, such as the 36th day of the month. The changeover from "summer time" to "winter time" by automatic means is not possible owing to the varying dates when these changes occur, but precautions have been taken to enable the adjustment to be made, without interfering with the service, by a member of the exchange maintenance staff.

Further Developments

Since the day of cut-over the automatic ticketing equipment has functioned smoothly, and the quality of the service has in every way fulfilled expectations. The exchange is being maintained by the regular maintenance staff and no unforeseen difficulties have been encountered. Evidence of the impression the system has made is furnished by the fact that a further order was placed on November 4, 1936 with the Bell Telephone Manufacturing Company for four new automatic exchanges for the towns of Zeebrugge, Heyst, Knocke, and Le Coq, all in the Bruges rural area. For these exchanges, which are to be in service in time for the summer season of 1937, automatic ticketing is specified for all rural calls for which the charge exceeds the local call fee. The centralisation of all printing registers at the toll switching centre, Bruges, represents a further advance in the art and constitutes another advantage over multi-metering, inasmuch as the tedious collection of meter records from outlying localities is avoided. It is intended to give an account of the measures taken to attain this end, and to describe in greater detail, in a separate article, the mechanical features of the printing register.

Automatic Printing Register for Telephone Call Recording

By L. DEVAUX,

Les Laboratoires, Le Matériel Téléphonique, Paris, France

THE trend towards the adoption of full automatic switching systems for toll connections has created a demand for a recording mechanism which can produce automatically a charge ticket for each call, corresponding to the tickets prepared by the operators in manual switching systems. Such an apparatus, known as a printing register, has been developed by Les Laboratoires L.M.T.; it is believed to be new in the telephone art, and has been widely protected by patents.

Function of the Printing Register

The object of the printing register is to produce a separate ticket for each call established through the trunk with which it is associated. On the ticket, the following indications are recorded: the called subscriber's number, the charge per time-unit of conversation, the calling subscriber's number, the date and time of day of the connection, the identification mark of the machine which has made the ticket, a serial number and the number of elapsed time-units of conversation.

The ticket printer is an electro-mechanical apparatus operated by impulses delivered by the automatic central office equipment; its functions are to record all indications delivered to it in sequence by the automatic equipment, and to send alarm and suitable status signals to the latter.

A ticket is made from a continuous strip of thick paper wound on a roll; the numbers are printed, the elapsed time-units are recorded by punched holes, then the tape is severed and the ticket is ejected. The printing of the subscribers' numbers and the charge per time-unit is made digit by digit. The date, the time of day and the serial number are printed in three operations, one for each. The duration of the connection is recorded by punched holes which are made one by one at the beginning of every minute, except that the first three-minute unit is recorded by three holes shortly after the called subscriber answers.

The printing register is necessarily a rather complicated piece of apparatus, and the description which follows is intended to give only a general idea of its principle of operation inasmuch as a complete description would occupy too much space.

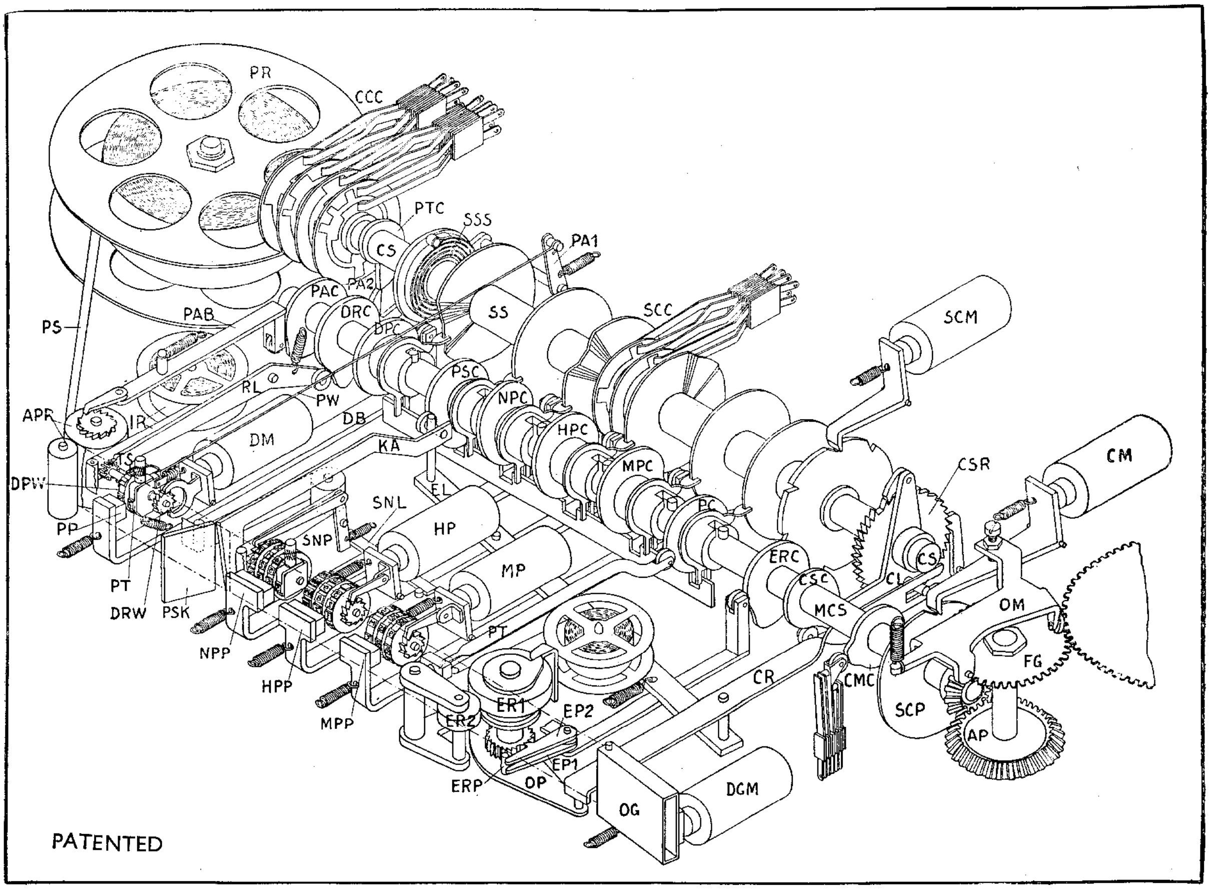
Mechanical Principle

The mechanism is shown schematically in a simplified form in the figure (page 274). In order that certain parts might be illustrated, it has been necessary to depart somewhat from the actual structure of the apparatus.

The mechanical operations of the printing register are controlled by three revolving shafts: main cam shaft MCS, counting shaft CS and shifting shaft SS. Mechanical power is imparted exclusively to the main cam shaft, and is conveyed thence by cams only. The main cam shaft is driven by a continuously rotating vertical shaft through a flexible gear in the same way as in the Rotary Automatic telephone system, a method which more than twenty years of experience has shown to be satisfactory. The flexible gear is shown at FG; it drives the main cam shaft, MCS, through bevel gears AP.

Control of the register from the outside is effected exclusively by closing electrical circuits at appropriate times to operate a series of electro magnets DM, MP, HP, CM and DGM. The function of each is explained later.

The main cam shaft carries a number of cams; some are clutched and perform operations which are repeated at each revolution of the shaft; others are clutched in sequence. These latter cams are mounted on bushings which can slide freely on the shaft, each bushing having a slot acting as a dog for engaging a corresponding pin on the shaft. The sliding motion of each cam unit is imparted by an undulated disc, which is rigidly mounted on



Mechanism of Automatic Printing Register Shown Schematically in Simplified Form.

the shifting shaft SS and which passes between the prongs of a fork carried by the cam unit.

The cams are shown on the figure as follows :

PAC, paper advancing cam, always clutched ;

DRC, digit wheel resetting cam, always clutched ;

DPC, digit printing cam, clutched for printing subscribers' numbers and tariff ;

PSC, paper severing cam, clutched for severing the paper strip when the ticket is complete ;

NPC, identification mark and serial number printing cam, clutched for printing a serial number and a mark proper to the machine ;

HPC, hour printing cam, clutched for printing the time of the connection ;

MPC, date printing cam, clutched for printing the day and month ;

PC, punching cam, clutched for punching holes denoting the duration of the connection ;

ERC, ejecting roller spring winding cam, always clutched for winding up the clock spring of the ejecting rollers ;

CSC, counting shaft advancing cam, always clutched ;

CMC, clutch magnet and reverting impulse cam, always clutched for operating contact springs ;

Ink ribbon advancing cams not shown on the illustration, always clutched.

A stopping and centering disc, SCD, is clamped on the main cam shaft ; it contains a notch which is engaged by the tip of the armature of the clutch magnet to fix exactly the home position of the main cam shaft.

Cycle of Operations

The cycle of operations consists of 36 or more revolutions of shaft MCS and one revolution each of shafts CS and SS. In consequence of the latter, CS and SS can be concentric and interrelated by a spring drive. Counting shaft

CS has 36 positions and is rotated step by step, one step for each revolution of main cam shaft MCS, winding up the clock spring, SSS, which drives shifting shaft SS.

A ticket is made from the paper strip, PS, which is advanced step by step by the rotation of cam shaft MCS ; the normal ticket, accordingly, has a length of 36 steps.

Shifting shaft SS has seven positions and is advanced by the unwinding of the driving spring under the control of an escapement carried by the armature of a magnet, SCM. It sets the printer to enable it to perform seven distinct and selectable functions in sequence, namely : printing a digit, printing the date, printing the time of day, printing the serial number, punching a hole, advancing the paper without printing or punching and separating the tickets.

The interaction of shafts CS and SS is controlled within the printing register by electrical circuits closed by contact cams CCC and SCC on the two shafts, respectively. Regular Rotary sequence switch cams and spring nests are used.

Printing Numbers

The register, initially, is prepared to print the digits of the subscribers' numbers and the charge per time-unit ; the dog of the digit printing cam, DPC, is engaged by a pin of the main cam shaft, MCS, as shown.

The paper strip, PS, wound on a roll, PR, is fed into a channel (not shown in the illustration) and is advanced step by step by a pair of friction rollers, APR, which are controlled by a ratchet wheel and a pawl. The paper first passes in front of the digit printing wheel, DPW, an ink ribbon, IR, being inserted between paper and wheel.

The digit printing wheel is under the pressure of a spring through a pinion and a toothed sector, TS, and is held in position by a ratchet wheel, DRW, engaged by an escapement anchor carried by the armature of a controlling magnet, DM. Besides the digit printing wheel, DPW, there is a prefix type, PT, which at the beginning is in position to be printed on the paper.

The controlling magnet, DM, receives external impulses corresponding to the first digit. The escapement pawl oscillates and the type wheel rotates step by step under the action of the spring of the toothed sector ; the first digit is now opposite the paper strip as it is actually shown in the illustration. An impulse is next sent to the clutch magnet, CM, and the cam shaft, MCS, makes one full revolution, driving the digit printing cam, DPC, and the digit wheel resetting cam, DRC, the latter being rigidly fixed on the shaft.

The first cam moves a bar, DB, carrying a printing pad, PP, which applies the paper strip both to the digit type of the wheel and to the prefix type, which are thus printed. Immediately afterwards, the resetting cam, DRC, moves the resetting lever, RL, which drives the type wheel to its home position by means of the toothed sector, TS. During the resetting operation the paper advancing cam, PAC, fixed on the main cam shaft, acts upon a bar, PAB, which drives the rollers, APR, by means of a pawl and a ratchet wheel, and the paper strip is advanced one step.

A fourth cam, CSC, drives the cranked lever, CL, bearing a pawl which rotates the counting shaft, CS, through an angle corresponding to one tooth of the ratchet wheel. This small rotation of the counting shaft disengages the prefix type, PT, so that it will not again be printed. The prefix type is pulled by a wire, PW, secured at the end of an arm, PA1, fixed to a second arm, PA2, the end of which bears upon a spiral cam, PTC, on the counting shaft. When this shaft rotates, the end of arm PA2 escapes from the end of the spiral cam and, under the action of its spring, the arm PA1 pulls the prefix type, which rotates and becomes disengaged.

The same cycle of operations is repeated for all the digits (seven on the first model) of the number to be recorded first ; that is, the called subscriber's number, the paper strip advancing each time by one step, and the counting shaft rotating one tooth.

When all the digits of the first number are printed, the counting shaft is in position 8, where a contact closed by one of its cams, CCC, causes the clutch magnet, CM, to become energised. The cam shaft rotates twice, causing the paper to advance two steps and the printing pad to press the paper strip on the digit wheel, but since no digit is displayed, two dashes only are printed and serve to separate the first number from the second.

The counting shaft, CS, is now in position 10, and the printer is ready to receive the digits of the tariff exactly in the same way as for the first number. At this moment a reverting signal is sent to the automatic exchange. Four digits are allotted for the charge per time-unit, and the counting shaft moves to position 14 where it again causes the main cam shaft to make two revolutions, and two dashes are printed.

The counting shaft moves to position 16 and signals again by a reverting impulse that it is ready to register the calling subscriber's number; this latter number of 6 digits is printed in the same way, and the counting shaft moves to position 22.

All numbers are now completely printed and the digit printing mechanism is placed out of action as explained subsequently.

During the printing of the numbers the paper strip passes between the blades of a cutter, PSK, and, when these operations are completed, it arrives in front of the date (month and day), the time of day (hour and minutes), and the serial number of the printer which are shown, respectively, at MP, HP and SNP.

The printer must now be set to register the first chargeable period of conversation.

Printing the Date, Time of Day, etc.

The shifting of the mechanism is accomplished by the shaft, SS, which, as already stated, carries undulated discs which control the clutching of the operating cams of the main cam shaft.

The contact cams of the counting shaft close the circuit of the shifting shaft controlling magnet, SCM, which operates an escapement pawl, causing the shifting shaft to rotate under the action of a clock spring, SSS. Consequently, the digit printing cam, DPC, is declutched and two other cams are clutched: the punching cam, OC, which drives a punching tool, PT, and the date printing cam, MPC, which drives a pad, MPP, for applying the paper strip to the type wheels of the month and day printer, MP. This latter apparatus resembles a message register; it is controlled by a master clock which sends an impulse at midnight every day for advancing the wheels.

The printer now sends a reverting impulse for signaling that it is ready to receive an impulse, indicating the beginning of a chargeable period. When this latter impulse arrives and energises the clutch magnet, CM, the main cam shaft makes one revolution: the date is printed, a first hole is punched, the paper is advanced one step, and the counting shaft is driven to position 23.

In this position, the circuit of the shifting shaft controlling magnet, SCM, is again closed locally and the shifting shaft rotates, freeing the date printing cam, MCP, and clutching another cam, the time of day printing cam, HPC, controlling the printing pad, HPP, in front of the wheels of the time of day printer, HP. This latter is similar to the date printer and its type wheels are operated every five minutes by impulses delivered by a master clock.

As soon as this cam shifting operation is completed, the contact cams of the shifting shaft close the circuit of the clutch magnet and the cam shaft makes another revolution for printing the time of day and punching a second hole.

A cycle of operations, similar to the preceding one, occurs for shifting the cams: the hour printing cam, HPC, is freed, the serial number printing cam, NPC, is clutched, after which the cam shaft makes a third revolution. The pad, NPP, applies the tape to the fixed types and type wheels of the serial number printer, SNP, for printing identifying marks denoting the machine printing the ticket and a serial number set by number wheels. These wheels are advanced by one unit for every ticket made by the machine by means of a pawl driven by an oscillating lever, SNL, controlled by the printing bar of the time of day printer.

The counting shaft has been advanced each time for the two last operations and is now in position 25. All printing operations are now finished: serial number printing cam, NPC, is freed by the rotation of the shifting shaft, but the punching cam, PC, remains clutched.

Registering Duration of Conversation

The printing register is now ready to record the duration of the conversation. For this purpose, an impulse is sent at the beginning of every minute (after the first three minutes) by the automatic exchange equipment in order to energise the clutch magnet, CM, and to rotate the main cam shaft once, causing a new hole to be punched each time, as well as the paper and the counting shaft to be advanced.

As the normal ticket is made in 36 steps, there is room for 11 holes in addition to the first 3, corresponding to a conversation of 14 minutes' duration. After this time, the counting shaft is in position 36 in which the driving pawl bears upon a part of the rim of the ratchet wheel, CSR, where a tooth has been removed ; thus, if more time punching impulses are received, the paper is punched and advanced, but the counting shaft is no longer driven, remaining in position 36. A ticket longer than the normal dimensions may thus be made for a practically unlimited conversation.

Frequently the time allowed for a toll connection is limited to 6, 9 or 12 minutes, according to the intensity of the traffic. The printing register provides a simple method of interrupting the conversation after the maximum allowed time has elapsed. The position of the counting shaft denotes the duration of the conversation ; it is in position 25 during the first three minutes. It passes to position 26 at the beginning of the fourth minute when the time impulse is received, and so on. The contact cams of the counting shaft are arranged to send a reverting impulse either in position 28, 31 or 34, at the beginning of the 6th, 9th or 12th minute of conversation, so that the automatic exchange equipment may send at the proper moment a signal over the line informing the subscribers that the connection will shortly be broken, and may then make the disconnection.

Completion of the Ticket

At the end of the conversation, when the automatic equipment releases, the printing register advances the ticket up to 36 steps, provided this position has not already been reached as a result of the duration of the conversation. If the counting shaft is already in position 36, the conversation has lasted 14 minutes or more and the ticket is of normal length or longer.

In the first case, when the clearing signal is received, the shifting shaft is rotated to declutch the punching cam, PC, without clutching another cam. Then the clutch magnet, CM, is energised and the main cam shaft rotates continuously until the counting shaft reaches position 36. During this operation the paper is advanced step by step without being punched. Since the counting shaft is then in position 36, the shifting shaft, SS, rotates one position and the paper severing cam, PSC, is clutched.

In case the disconnection occurs when the counting shaft is already in position 36, the shifting shaft, SS, rotates two steps and the paper severing cam, PSC, is clutched.

The rotation of the main cam shaft occurs immediately afterwards ; the paper strip is pressed against the knife, PSK, by lever KA, driven by cam PSC, and is severed. The ticket is now detached ; it must be ejected into a chute. This operation is achieved by a ticket ejector composed of two friction rollers, ER1 and ER2. One of them, ER1, is provided with a clock spring which is wound up step by step by a pawl, EP1, and a cam, ERC, of the main cam shaft during the preparation of the ticket, but the roller, ER1, is prevented from turning back by a second pawl, EP2. The knife armature, KA, drives a long lever, EL, which, by means of bar CR, oscillating plate OP and pin ERP, disengages both pawls, EP1 and EP2, just after the ticket is separated and, at the same time, it acts on a spring (not shown in the illustration) to apply the second roller, ER2, to the first one, the ticket being pressed between them. Under the action of the clock spring, both rollers rotate rapidly and throw the ticket through the oscillating guide, OG, into an appropriate chute.

The lever, EL, has another function : it drives the counting shaft out of its 36th position to reset it at its starting position. For this purpose, a double operation is imparted to the driving pawl, which is thus carried beyond the dead position of the missing tooth in the ratchet wheel, CSR ; the pawl being actuated through the agency of the connecting rod, CR, which links lever EL with the cranked lever CL. After this, the shifting shaft rotates one step more to free the paper severing cam, PSC, and to clutch again the digit printing cam, DPC.

The printing register is now in its starting position ready to print another ticket. The associated trunk, kept "busy" during the interval required to complete the ticket, is now free.

Special Tickets

The above sequence of operations takes place for a regular "effective" connection, but means have been devised to have the machine take care of "premature release" and "no reply calls." In both cases, when the disconnecting signal is received, the shifting shaft is rotated to unclutch all cams ; then the main cam shaft is rotated to complete the ticket to the normal length exactly as in the case of a regular ticket, but without any further recording. Severing and ejection are accomplished exactly as for a normal ticket.

In accordance with automatic telephone practice, a routine test circuit is associated with a set of printing registers. Test tickets are made to check the operation of the apparatus ; but, in order to facilitate maintenance, it has been found advisable to prevent the test tickets from being associated with the regular tickets. The oscillating guide OG, in its normal position, directs the tickets into the chute of the regular tickets ; when a test ticket is to be made, the test equipment closes a circuit to energise magnet DGM which deflects the guide, OG, so that test tickets are thrown into a separate chute.

Additional Features

The above description gives an idea of all the essential features of the printing register ; however, mention should be made of some of the patented refinements and safeguards which have been added to ensure satisfactory and reliable operation :

1. Alarm contacts signal when the paper roll is exhausted and when, for any reason, the printing register fails to accomplish its full cycle of operations.
2. A push button is provided to allow test tickets bearing only the date and the time of day to be produced for checking the position of the wheels.
3. The date and time of day printers may be advanced by push buttons in case they are late.
4. Interlocking devices prevent the disturbance of the relative positions of the counting and switching shafts.
5. The printing register is jacked-in on the bay and can be easily removed ; it is put in action and the corresponding trunk is rendered free only when it is fully jacked-in and clamped in position.
6. If the shafts of the printing register are not in their normal positions when it is placed on the bay, it resets itself automatically as soon as it is clamped.
7. When a new roll of paper is inserted, the printing register automatically makes a first blank ticket so that the next ticket will commence exactly at the right place.
8. When a printing register is engaged in recording a connection, it cannot be disturbed : date and time of day checking tickets cannot be made until this printer is free, the push-button being locked.

Field Trial

The automatic printing register above described is no longer in the experimental stage. A number of these machines are in service in the toll exchange in Bruges, Belgium. Particulars of the equipment used are given in another article in this issue of *Electrical Communication*, including views of the printing registers and the equipment bay on which they are mounted.

Application of Lorenz Communication Technique at the Olympic Games, Germany, 1936

By H. DEWALD,

C. LORENZ, A.G. Berlin-Templehof, Germany

THE great Olympic Games in Germany not only brought the finest sportsmen in the world to the arena and demanded from them the last ounce of bodily strength and athletic ability, but also imposed the highest demands on a large number of others who were engaged on the organization of the Games and who were responsible for their running smoothly. Not least amongst those who contributed to the solution of the important problems involved, was the Engineer.

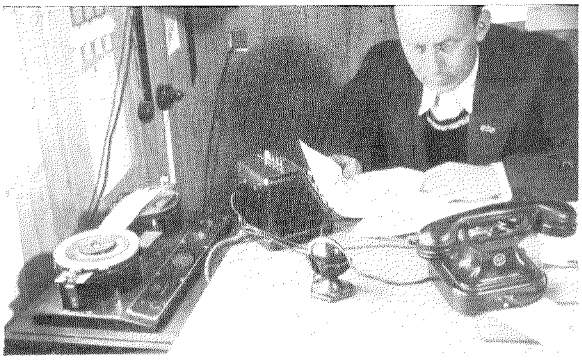
The organizing committee to a special degree, entrusted C. Lorenz, A.G., with many and important technical problems. The following Lorenz communication equipment was installed, i.e.:

16 Teleprinters, model 15.
220 Speech input amplifiers, V.35.[1]
4 Short-wave broadcast transmitters (Olympic World transmitters), each of 40 kW output.
5 Microphone amplifiers.
1 40 watt commentator's transmitter with modulation amplifier.
1 Steel band tape machine.
46 Steel wire machines ("Textophone").

It was essential that the different and widely separated playing fields be interconnected for co-ordination purposes. Accordingly, the Lorenz page teleprinter was utilized at the Olympic Winter Games held at Garmisch-Partenkirchen (February 1936).

Lorenz Teleprinter in the National Sports Field, Berlin.

Here the Press Office was connected to the Ski Jumping ground, the Ice-stadium and the Riessersee Ice-rink. The Lorenz page printers, which were available for local service in Garmisch-Partenkirchen, were connected in series, so that all communications from any one station were simultaneously received at all stations and could immediately be read from the complete manuscript for further transmission over loud-speakers. Results which were, for example, announced at the Ski Jumping ground, immediately appeared at the Press Office, the Ice-stadium and on the Riessersee. Thus the press representative, located at the Ice-stadium, was furnished with information on events taking place elsewhere.



Lorenz Steel-tone Wire Machine ("Textophone") installed in the Office of the Director of the Organization Committee in Garmisch-Partenkirchen (Control Station).

Duplicating apparatus placed alongside of each page printer provided means for quickly reproducing any desired quantity from the ten copies delivered by the page printer. These copies then immediately became available to the press agents.

The Press Office also had two additional Lorenz page printers. One machine was connected with the Government Office of German Correspondence, Berlin, Zimmerstrasse, whilst the other was connected with the office of the "Münchener Neueste Nachrichten" which printed the programme.

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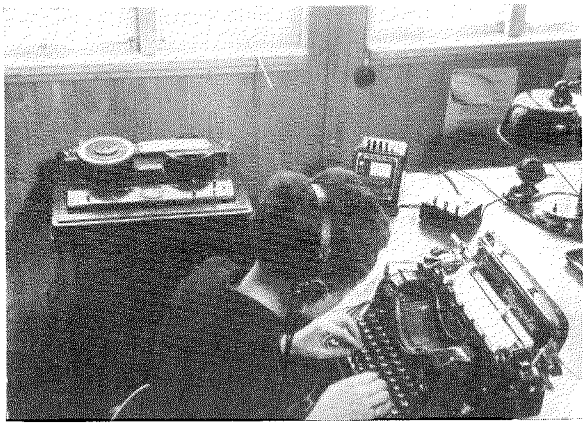
[1] This equipment was installed by the Reichs-Rundfunk-Gesellschaft.



Lorenz "Textophone" Listening Station.

The service was rapid and efficient. The assignment of experienced and expert operators from the Reichspostdirektion München ensured correct and reliable transmission of news.

The teleprinters were equipped with an automatic call-back device which, when the appropriate key was depressed, printed the name of the place where the communication originated. In the case of the apparatus at the Ski Jumping ground, for example, when the key was depressed the words "Ski Jumping ground" appeared at the transmitting point and, simultaneously, it was printed by all the interconnected printers. A great deal of time was thus saved since the release of the identifying word was accomplished by depressing a single key.

At the XIth Olympiad in August, 1936, in the Reich sports-field, Lorenz teleprinters were installed in the Führer's box, the Government box, the Judges' box, and in the Olympic World Broadcast Transmitting Room. All were connected with the teleprinter-exchange, and from it received pertinent news items. Lorenz teleprinters were also installed in the show-windows of important business houses and newspapers, in order that passers-by might receive news of the Olympic competitions transmitted by the teleprinter-exchange in the sports-stadium.

Of the 220 speech input amplifiers (V35) supplied to the Reichs-Rundfunk-Gesellschaft, 50 were installed at Garmisch-Partenkirchen and 170 in various locations, such as the Reich sports field, the Deutschlandhalle, the bicycling track, and the regatta river banks in Grünau, near Berlin, and Kiel. Thirty-three foreign broadcasting companies in co-operation with the Reichs - Rundfunk - Gesellschaft, transmitted news of the Olympiad in thirty-two countries. Sixty-seven foreign radio stations distributed this news in twenty-five languages throughout the world. Such figures show very clearly the interest and the world participation in the Berlin Olympic Games. At the same time, the tremendous requirements imposed on German radio facilities will be apparent. These could only be met with the aid of the most modern technical equipment.

A series of fixed speech input points was provided, equipped with type V35 amplifiers. Sports fields from which a large number of commentaries had to be sent were provided with sub-stations which, in some cases, as regards size and scope, exceeded the amplifier-equipment of an ordinary broadcasting station. These sub-stations totalled 17, the largest being placed in the underground room of the principal competitors' stadium. The latter functioned as the principal amplifier-station and, also, as the main switching station. Here all the lines from the sports fields, from the Avus, the Deutschlandhalle, the bicyling stadium and the regatta waters in Grünau and Kiel terminated. In addition to these fixed speech input points, a number of mobile stations were provided on lorries containing Lorenz built-in apparatus.

By means of this speech input equipment it was possible to meet all the requirements of the organization engineers involving the selection of the microphones set up at various points, regulation of sound volume and the mixing of several microphone circuits. The equipment is of the transportable type and is furnished with the usual broadcasting valves which amplify the speech currents to values comparable with those supplied to cable circuits when normally sensitive condenser-microphones are employed. Facilities were provided for measuring the input voltage of the cable, and supervising the transmission at the entrance to the cable, as well as for transmitting an interval signal between broadcasts. The speech input equipment consists of regulator-panels (regulator and mixing equipment), amplifiers proper, monitoring amplifiers, the modulation tester and the interval signaller. Each equipment unit comprises four regulator panels which, at their input, permit selective connection of any two condenser-microphones by means of a switch.

The monitoring amplifier stage serves for supervising the outgoing modulation voltages at the speech input equipment itself. It is coupled through a volume regulator directly to the anode of the output valve. The output amounts to about 0.6 watts and suffices to modulate the permanent dynamic loudspeaker serving as a monitoring speaker.

An 800 cycle note, keyed by a relay arrangement, was selected for the interval signal. The note itself is obtained from a valve generator. The complete electrical separation of the interval-signaller from the amplifier enables an interval signal to be transmitted on the cable whilst a transmission test is being made at the transmitting-end.

As a special extension of the German Reichspost's largest short-wave broadcast system, Lorenz supplied 4 short-wave transmitters, each with a 40 kW output. The new transmitters, representing the results of lengthy development, had to comply fully with the following requirements: telephone output 40 kW[2]; maximum frequency stability; modulation 80 per cent.; and rapid wavelength change-over. The first requirement not only involves a valve problem, but also a question of circuit practice and construction from a high frequency aspect. In the short-wave range, the most favourable waves are close together. In order, therefore, to avoid mutual interference, it is of great importance that the theoretical frequency of the transmitter be maintained as accurately as possible. For this reason, the new transmitters, each of which has 7 stages, were equipped with quartz control at a frequency precision of 10^{-6}. Tests made thus far have shown that the new transmitters, in consequence of their ample output when class B amplifiers are used, permit of a modulation of nearly 100 per cent.

A medium-wave broadcast transmitter operates uninterruptedly on the same wave length with the same antenna. In the case of short-wave transmitters, on the other hand, the antenna and wave are often changed during the day. In order to facilitate tuning, the new transmitters are constructed with duplicate tuning equipment. While the transmitter is operating on one wave, the other tuning equipment is prepared for the next wave. The switching-over period, which in the case of older short-wave transmitters takes from 20 to 30 minutes, is thus decreased to seconds.

The output stages of the short-wave transmitter have water-cooled valves. An extensive cooling system with a large number of pumps, copper-pipe cooling coils and enormous water-conditioning tanks ensures the necessary cooling water supply at all times.

The four short-wave transmitters form the centre of a directional antenna system. The antenna systems radiate electric waves to North, Central and South America, to Africa and to South and East Asia. In order to obtain the most favourable conditions for short-wave transmission, depending on the time of the year and the day, two or three waves must be provided for each direction.

The distributor-amplifier, developed by Lorenz in co-operation with the Reichs-Rundfunk-Gesellschaft, was also installed for the Olympic Games. In the case of high-power transmission the plurality of microphones used in connection with broadcasting and tone films often causes interference. As a result of the arrangement of the technical equipment, architectural problems were encountered; and further, conflicting technical requirements were

Olympic Transmitter at Garmisch-Partenkirchen with the Lorenz Speech Input Amplifier (V35).

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[2] According to the recommendations of the C.C.I.R., the term telephone output should be understood to mean antenna-output in the case of non-modulated transmitters.

difficult to avoid. As a general rule, therefore, only two microphones, a main pair and a reserve pair, were used; and distributor-amplifiers were installed for supplying the individual amplifier equipment of all the connected sound transmission and sound recording systems.

To avoid interference as far as possible, these amplifiers were constructed with special care and with high grade components. A separate spare amplifier was also provided, each amplifier having duplicate batteries for filament and plate currents, so that uninterrupted transmission and maximum possible reliability were secured.

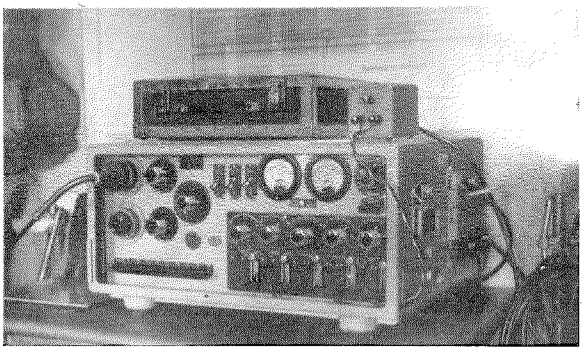
A convenient monitoring control at the individual outputs of the distributor amplifier was provided by an amplifier stage equipped with head telephones. A step-by-step switch was used for the necessary switching operations. The "O" stage was shunted over a 200 ohm resistance so that the listener might control the operation of the monitoring stage.

The whole amplifier was installed in a chassis consisting of a frame and front plate. The chassis was inserted in a light weight metal case projecting beyond the front plate and thus protecting components mounted on the latter. The batteries were housed in a second similar case made of iron sheeting to resist corrosion from the caustic potash contained in the Edison batteries.

Olympic Transmitter Hut at Garmisch-Partenkirchen.

Of special interest was the introduction of a Lorenz commentator's transmitter which the announcer carried about with him. Commentaries were transmitted to a conveniently placed receiver, and then conveyed to a transmitter or recorded on gramophone records. Practically all communications could be conveyed to the broadcasting system by means of such commentators' transmitters.

In the Olympic Games held in Berlin, the "steel sound car" of the Reichs-Rundfunk-Gesellschaft, equipped with two Lorenz steel-tone tape machines for recording and subsequent transmission purposes, was utilized. For the Winter Olympic Games at Garmisch-Partenkirchen, Lorenz provided a steel-tone tape machine for use in connection with the Bob Sleigh Track. Events in this section, therefore, could be announced quickly and satisfactorily at other points, such as at the Ice-stadium and the Ski Jumping ground.[3]



Lorenz Distributor Amplifier.

This steel-tone tape machine, developed by Lorenz to a high degree of perfection, was installed at a control tower on the Bob Sleigh Track, and was operated through a microphone by an observer in the tower. During intervals between events, the record on the steel tape was reproduced at the Ice-stadium and Ski Jumping ground by loudspeakers.

Lorenz steel-tone wire machines, called "Textophones," were installed in the office of the Organization Committee in the Hardenbergstrasse, in the Schillersäle, in the Deutschlandhalle, in the Sports House and, particularly, for the National Sports Organizer, Herr von Tschammer und Osten, and in the National Sports Field.

During the Olympic Winter Games in

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[3] See *Electrical Communication*, "The New Steel Tone Tape Machine," Vol. 15, No. 1, p. 62.

Garmisch-Partenkirchen, "Textophones" were used by the Olympic Committee and proved highly satisfactory. They enabled all the Sports Organisers to furnish their colleagues with necessary instructions regarding individual arrangements over ordinary telephone lines. The machines also were especially useful in recording important conversations for certain persons who were temporarily absent.

A "Textophone" switchboard, which consisted of a combination of several "Textophone" machines with a switchboard connected in parallel to the exchange lines, was installed in the Hardenbergstrasse in Berlin. It was thus possible also to record urgent telephone messages for an absent subscriber. On his return he could listen to the conversation direct from the machine ; or, if it were known that his absence would be prolonged, the conversation could be recorded from the machine by a typist in written form.

In addition to these "Textophone" exchanges, whereby it was possible to record conversations from ten exchange lines, important members of the Organization Committee had "Textophone" machines connected to the telephone as a substitute for a second receiver. Telephone conversations could consequently be recorded on the steel wire. With the aid of the "Textophone" every important telephone conversation could thus be recorded and listened to again at any desired time.

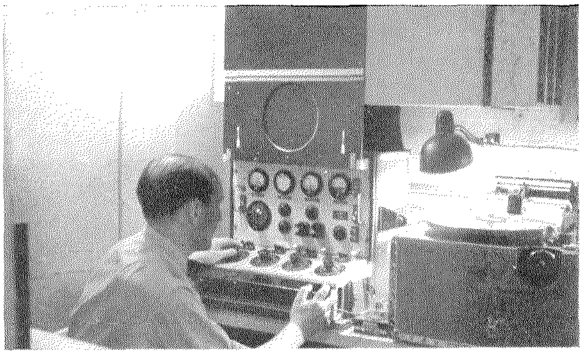
For quicker reference to any individual conversation or dictation recorded on the "Textophone" wire, the time of such conversation or dictation is marked on a ruler-type writing block on the right-hand side of the coil carrier. The edge of the block is also correspondingly subdivided in twenty minute intervals. The return to the desired listening point occupies only a very short time, inasmuch as the wire reversing operation is twice as fast as the forward movement during recording.

The "Textophone" control set can be in a separate room from the recording apparatus. It consists of a small desk type cabinet with 5 push buttons, a table microphone and a special control headphone.

The listening set itself is preferably set up close to the "Textophone." Associated therewith is a switch box with 3 keys, a volume regulator and a pair of headphones. For listening to the recorded text, the switch which is marked accordingly is thrown to "Listening Position." The indicator signal at the control station then drops out of sight, indicating that the set is no longer connected with the "Textophone." The key marked "W" (Reproduction) is then pressed and the volume adjusted to the required degree by a knob. During the recording process, the sound carrier movement of the "Textophone" is disconnected. This is accomplished at the listening point by pressing the key marked "H" (Stop). The special wire used as a sound carrier then runs back a little way so that, during further listening, by pressing down the key "W," the last part of the recorded text is repeated, thus aiding in securing continuity of the text.

The foregoing indicates the extent to which C. Lorenz, A.G., participated in providing communication facilities on the occasion of the Olympic Games in Berlin and in Garmisch-Partenkirchen. As a result of high standards of development in the communication field, Lorenz were able to provide high grade apparatus and equipment in the great numbers required within a comparatively short time, thus contributing to the success of an outstanding achievement.

Acknowledgment is due to the Press Agent of the IVth Olympic Winter Games in Garmisch-Partenkirchen and to the Organization Committee of the XIth Olympic Games in Berlin, for expressions of appreciation to C. Lorenz, A.G., emphasising the satisfactory operation of the Lorenz Communication Equipment.



Lorenz Speech Input Amplifier (V35) for Gramophone Recording Reception in the National Sports Field, Berlin.

The Carrier Telephone and Telegraph Equipment of the New Bass Strait Submarine Cable System

By F. RALPH, B.Sc., A.M.I.E.E., and R. L. HUGHES, B.Sc., A.M.I.E.E.,

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The submarine telephone cable system between the Australian Mainland and the island State of Tasmania is described. The cables are of the type employing a single non-loaded central conductor with coaxial return. Six telephone circuits and a programme circuit are provided together with telegraph facilities. The terminal and intermediate circuits and equipment are described, and the land line extensions on the mainland and in Tasmania are dealt with. The system represents the first case in which reversed feedback type amplifiers have been used in commercial practice. Overall transmission results are given.

Introduction

THE first public telephone service between the mainland of Australia and Tasmania was inaugurated on March 25, 1936, by the Prime Minister of the Commonwealth, the Rt. Hon. J. A. Lyons, M.P., who declared the service open in an address from Canberra, which was transmitted to Tasmania over the new cable and broadcast throughout the Commonwealth.

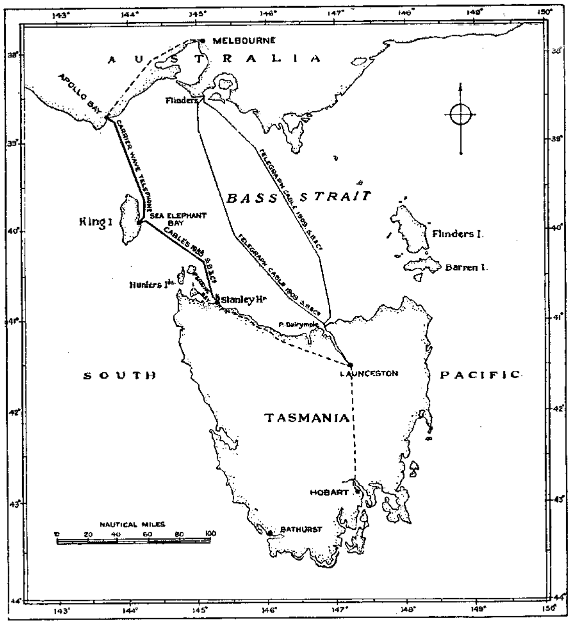

Fig. 1—*Map of Route.*

The need for telephone communication between Tasmania and the mainland had been keenly felt for many years, but in spite of its desirability, having regard to the telephone facilities existing between the other States of the Commonwealth, technical difficulties had hitherto made its realisation at a reasonable cost impracticable.

The number of channels of communication which it was estimated would be required would have made the use of radio channels expensive, both in initial and maintenance costs, while considerations of fading and the need for secrecy were important factors.

As the shortest practicable routes for a direct cable were of the order of 145 nautical miles, and the depths rendered the use of a multiconductor lead-covered cable inadvisable, the problem of providing a number of channels by means of a cable was a considerable one. In recent years, however, improvements in the dielectric materials used in submarine cables have made it possible so to improve the transmission properties of such cables at high frequencies that the Bass Strait problem was brought within the practicable economic range. It was finally decided to employ a submarine cable to provide the desired facilities; also, to lay the cable on a route calling at King Island, about half-way between the mainland and Tasmania, and by establishing a repeater station on the island, to increase the total number of communication channels obtainable and, at the same time, to provide a telephone service for the population of King Island.

Tenders were called for and the system designed by Standard Telephones and Cables, Ltd., was accepted, arrangements being made for the cable to be provided by Siemens Bros.

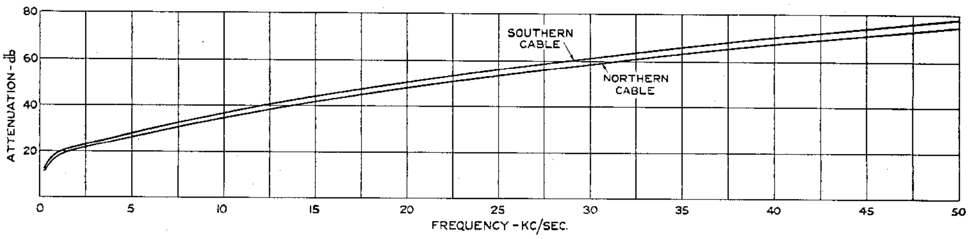

Fig. 2—Attenuation-Frequency Characteristics of Cable Sections.

to the design necessary for this system. The present article describes the system and the equipment supplied by Standard Telephones and Cables, Ltd., to provide the extensive communication facilities required on the cables and associated land line extensions.

Fig. 1 shows the route followed by the complete system. It is of interest to note that the submarine cable system is longer, and is operated with higher frequencies than any other submarine telephone cable system in the world.

Cable Route

The two cable sections are laid as follows. The first or northern section runs from Apollo Bay, on the coast of Victoria, to Naracoopa (Sea Elephant Bay) on the East coast of King Island. The southern section runs from Sea Elephant Bay to Perkins Bay, near Stanley, on the North-West coast of Tasmania.

The laid lengths of the two cable sections are :

Northern Section = 78.92 nautical miles.
Southern Section = 82.05 nautical miles.

Type of Cable

The type of cable employed is similar in general design to the Key West-Havana No. 4 cable[1] consisting of a single central insulated conductor with a coaxial uninsulated return conductor. No loading is used.

This type of cable is intended for the transmission, without excessive attenuation, of a wide range of frequencies such as are employed on carrier telephone and telegraph systems. The attenuation-frequency characteristics of the two cable sections are shown in Fig. 2.

Circuit Requirements

The total circuit requirements on the submarine cable were as shown in Table I.

TABLE I

Type of Communication Channel.	No. of Circuits Required.
Duplex Telephone	5
Duplex Telegraph (capable of a speed of 50 bauds)	7
Broadcast Programme (one way but reversible in direction of transmission) (Range 35 to 7000 p : s) ..	1

All of the communication channels were to be extended to Melbourne on the mainland and to Launceston in Tasmania ; at the Tasmanian end some channels were to be extended still further to Hobart.

Some only of the ultimate number of circuits were required initially, traffic estimates having suggested that the full number would not be needed until about 1940.

Table II shows the terminating points for the various circuits required for the initial installation and also for those to be provided later.

Further requirements, which cannot be readily indicated in a table, were as follows :

(1) With regard to the broadcast programme channel between Melbourne and Hobart, it was specified that Launceston should have access, for local use, to programmes passing in either direction, and alternatively should be able to transmit Launceston programmes to Melbourne and Hobart simultaneously, thus forming, as it were, a triangular system in which any one of the three stations could transmit simultaneously to the other two.

(2) One of the telephone channels between Melbourne and Launceston was to be arranged

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[1] "A New Key West-Havana Carrier Telephone Cable," by H. A. Affel, W. S. Gorton and R. W. Chestnut, *Bell System Technical Journal*, April, 1932.

so that Currie, on the West coast of King Island, should be an intermediate station—Currie to be provided with facilities for using the Melbourne-Currie and Currie-Launceston sections simultaneously.

CHOICE OF METHOD OF MEETING CIRCUIT REQUIREMENTS IN THE CABLE

In examining alternative methods by which the above circuit requirements could be met over the route as a whole, the following were important factors of which it was necessary to take account:

TABLE II

	Type of Communication Channel.	Melbourne-Launceston.	Melbourne-Hobart.	Total.
Initial .. Installation	Duplex Telephone	3	–	3
	Duplex Telegraph	3	2	5
	Broadcast Programme (reversible channel)	–	1	1
Later Additional Installation	Duplex Telephone	–	2	2
	Duplex Telegraph	1	1	2

(*a*) In view of the high cost of submarine cables, it was important that the frequency spectrum available for transmission should be exploited as fully as possible. As the number of communication channels to be provided was fixed, this problem, therefore, resolved itself into the provision of these channels in the smallest possible frequency range, thus leaving as much as possible of the total usable range free for later exploitation as traffic requirements might demand.

(*b*) The frequency bands employed by any carrier telephone or telegraph systems operated on the land line sections of the routes must be such as to co-ordinate suitably with systems already in use or likely to be used over part or all of the same pole routes, so as to avoid excessive inter-system crosstalk.

(*c*) For economic reasons it was important that the equipment should be so far as possible of standard design, although this aspect could not be subordinated unduly to the broader issues covered by (*a*) above.

An important technical factor affecting the choice of a method of operation over the submarine cable, was the degree of uniformity which could be economically obtained in the characteristic impedance of the cable. When carrier channels are operated on open wire lines, it is not, in general, possible to employ the same frequency band in both directions owing to unavoidable irregularities in line construction, and variability due to weather changes rendering balance conditions and freedom from crosstalk impracticable.

In the case of a submarine cable of the type employed in the present system, however, it is possible, by suitable methods of manufacture, to produce a cable whose impedance-frequency characteristic is very smooth, so that a network may be devised to give a high degree of balance over a wide frequency range. Furthermore, as the temperature at sea bottom does not vary greatly from time to time, a cable well constructed from stable materials may be expected to exhibit very stable electrical properties; and a high degree of impedance balance, once achieved, should endure within close limits, for a long period.

The degree of balance required to permit of balanced operation is, of course, a function of the attenuation of the cable and hence, in a given cable, of the operating frequency. In a given case, therefore, the degree and stability of balance obtainable will determine the frequency range over which balanced operation is possible.

In the present case it appeared that, for design purposes, balanced operation might be assumed to be possible at all frequencies up to approximately 10 kilocycles per second. Above 10 kc.

all duplex channels would require different frequency bands for the two directions of transmission.

From the above considerations, it was clearly uneconomic to employ any part of the frequency range below 10 kc. for the broadcast programme channel, since only a unidirectional channel was required and the advantages of balancing the cable impedance would be wasted.

The following further points arise from a consideration of the circuit requirements :

(1) The number of telegraph channels required is such that they clearly cannot be provided by direct current circuits, so that either high frequency carrier telegraph channels must be employed or a voice frequency carrier telegraph system must be operated over a carrier telephone channel. The latter alternative is much the more economical in the frequency band required, owing to the simplification of the filtering problem. This scheme was, therefore, chosen, and the number of telephone channels to be provided was increased from five to six.

(2) As only one telephone channel was to be available at King Island, the natural one to select was the voice frequency channel, using the normal commercial range from say, 200 p : s to 2800 p : s, thus avoiding the use of modulators and demodulators at this station.

Allocation of Frequency Bands

In the frequency range below 10 kc. it is possible to obtain three telephone channel bands of commercial width ; and, operating on a balanced or "two-wire" basis, these bands will provide three duplex channels (one of which is, of course, the voice frequency or physical channel).

Six other channel bands, giving three duplex channels with different frequency bands for the two directions of transmission, may be located between 10 and 31 kc., giving the required total of six telephone channels below 31 kc.

At the time at which the Tasmanian Cable scheme was designed, a carrier system for the unidirectional transmission of broadcast pro-

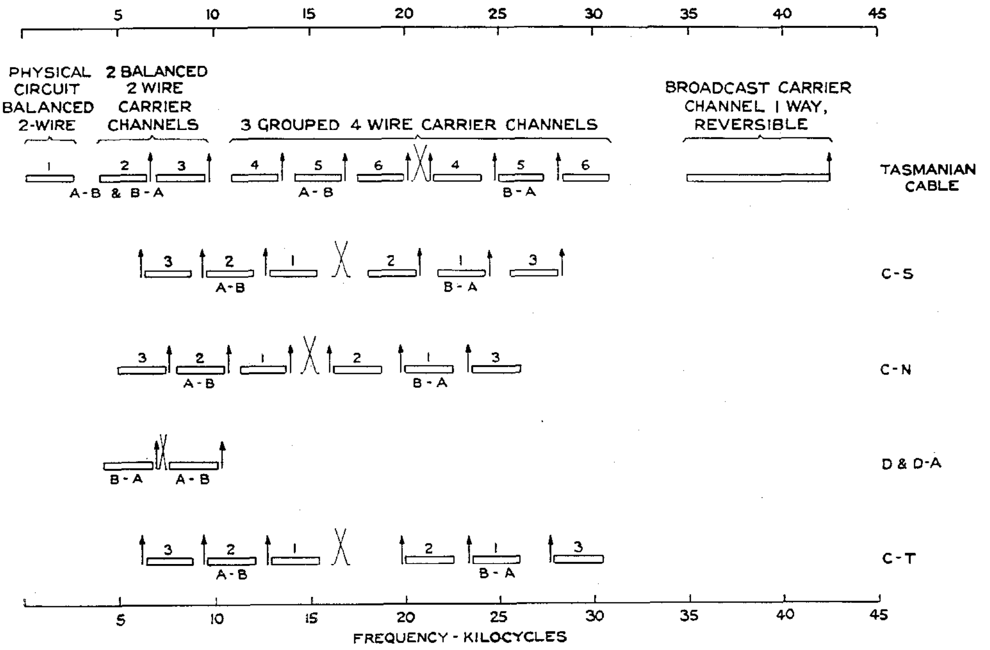

Fig. 3—Frequency Allocation Diagram of Cable Equipment and Relationship to Standardised Land Line Systems Already in Use in Australia.

grammes had already been standardised. This system employs a frequency band extending from 34 to 42.5 kc., and therefore fits in naturally and economically with the above allocation of telephone channel bands.

It was, therefore, apparent that such an allocation of frequency bands would represent the maximum economy in the utilisation of the available transmission range of the cable. This allocation of bands is shown diagrammatically in the top line of Fig. 3.

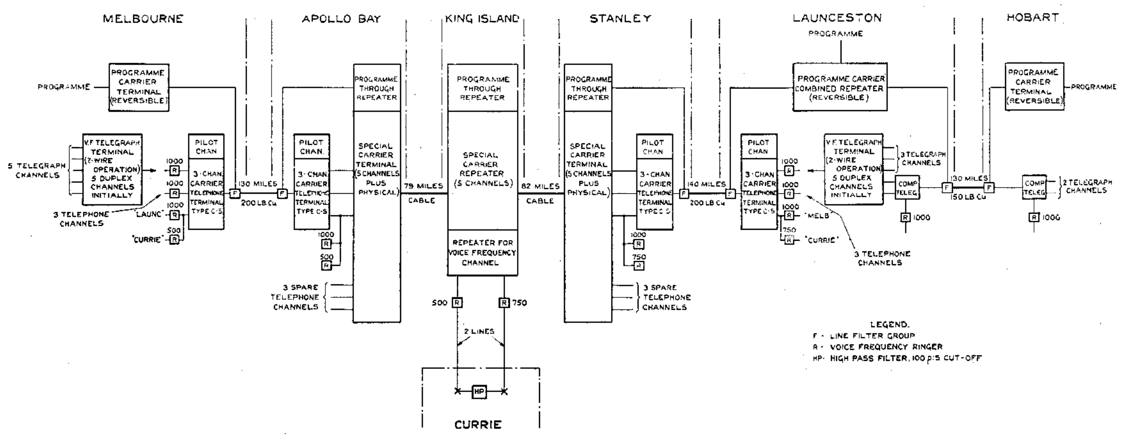
MELBOURNE
APOLLO BAY
KING ISLAND
STANLEY
LAUNCESTON
HOBART
PROGRAMME
PROGRAMME CARRIER TERMINAL (REVERSIBLE)
5 TELEGRAPH CHANNELS
V.F. TELEGRAPH TERMINAL (2-WIRE OPERATION) 5 DUPLEX CHANNELS INITIALLY
3 TELEPHONE CHANNELS
"LAUNC"
"CURRIE"
1000
500
R
PILOT CHAN
3-CHAN CARRIER TELEPHONE TERMINAL TYPE C-S
F
130 MILES
200 LB Cu
PROGRAMME THROUGH REPEATER
SPECIAL CARRIER TERMINAL (5 CHANNELS PLUS PHYSICAL)
3 SPARE TELEPHONE CHANNELS
79 MILES
CABLE
SPECIAL CARRIER REPEATER (5 CHANNELS)
REPEATER FOR VOICE FREQUENCY CHANNEL
500
750
2 LINES
HP
CURRIE
82 MILES
CABLE
140 MILES
200 LB Cu
750
PROGRAMME CARRIER COMBINED REPEATER (REVERSIBLE)
"MELB"
3 TELEGRAPH CHANNELS
COMP TELEG
130 MILES
150 LB Cu
2 TELEGRAPH CHANNELS
LEGEND.
F - LINE FILTER GROUP
R - VOICE FREQUENCY RINGER
HP - HIGH PASS FILTER, 100 p:s CUT-OFF

Fig. 4—General Diagram of Transmission System.

Co-ordination with Standardised Land Line Systems

It would seem, at first sight, that the channels in the cable could be extended to Melbourne and Launceston by land line without any change of the carrier frequencies. The "go" and "return" sides of the balanced cable channels would, of course, have to be carried in separate open wire pairs as it is not practicable to work balanced channels on open wire lines. The use of the same carrier frequencies throughout was, however, ruled out for the following reasons. Carrier telephone systems of various types are already in extensive use throughout the Commonwealth, and in order that such systems may be utilised to the fullest possible extent on a given pole route, care is necessary in planning installations to ensure that the frequency bands employed by systems operating on that route are so arranged that excessive inter-system crosstalk does not occur. The systems most commonly used in Australia employ the frequency bands used in the "Standard" systems types "D" and "D.A." (single channel) and "C-N," "C-S," "C-T" (three channel). The frequency bands employed by these systems are shown in Fig. 3 in relation to those already referred to for the cable equipment. From this diagram there are clearly two features of the proposed frequency allocation for the cable equipment which render it an unsuitable one for co-ordination with systems of existing design.

Firstly, the bands of the two balanced carrier channels coincide fairly closely with those of the single channel systems, and as the cable equipment would employ both these frequency bands in both directions, serious mutual crosstalk would occur. As there were such systems already operating between Melbourne and Geelong on the Melbourne-Apollo Bay route, this was an important factor.

Secondly, the upper channel of the "A to B" group of the cable frequencies coincides approximately with, and is transmitted in the opposite direction to, that of the lowest channel of the "B-A" group of the C-S and C-N system. This also would lead to serious crosstalk.

It is clear that no rearrangement of the frequency bands of the cable equipment could possibly avoid these crosstalk difficulties without reducing the number of channels obtainable.

General Scheme Finally Adopted

It was therefore decided to employ for the cable section of the route the general arrangement of channels already shown in Fig. 3 and to install terminal equipment (modulators, demodulators, channel band filters, etc.) at Apollo Bay and Stanley so as to make this section of the whole system complete in itself. Extension of the channels from Apollo Bay to Melbourne and from Stanley to Launceston and Hobart could then be achieved by using standard land-line carrier systems such as were already in extensive use in the Commonwealth. The choice of the particular systems to be used could then be made entirely on the basis of the requirements of the particular land line routes.

This scheme offered the further advantage of great flexibility, since at a later date the equipment on the land line sections of the route could be modified as general developments might demand, without in any way affecting the equipment on the submarine cable.

Fig. 3 indicates the actual band used for each direction of transmission on each of the six channels in the cable system. It will be observed that the balanced channels and the lower group employ the lower sideband. The use of the lower sideband rather than the upper is desirable for channel No. 2 as it prevents certain third- and fourth-order products of modulation from occurring within the range of the transmitted sideband.

A general examination of the frequency distribution of inter-channel modulation products, such as would be produced by an overload condition in a common amplifier, showed that little, if anything, was to be gained by a special allocation of the bands to individual channels. The upper sideband was chosen for the upper group as the maximum carrier frequency to be used was thereby slightly reduced.

The land-line system chosen in each case to provide the initial three through circuits was the type C-S three-channel system inasmuch as it may be operated on the same route as a type D system. For the later extension to six channels, type C-T systems will be used. The carrier programme system operates on the same pair of wires as the three channel system and is provided with straightforward reversible repeaters at the three cable stations.

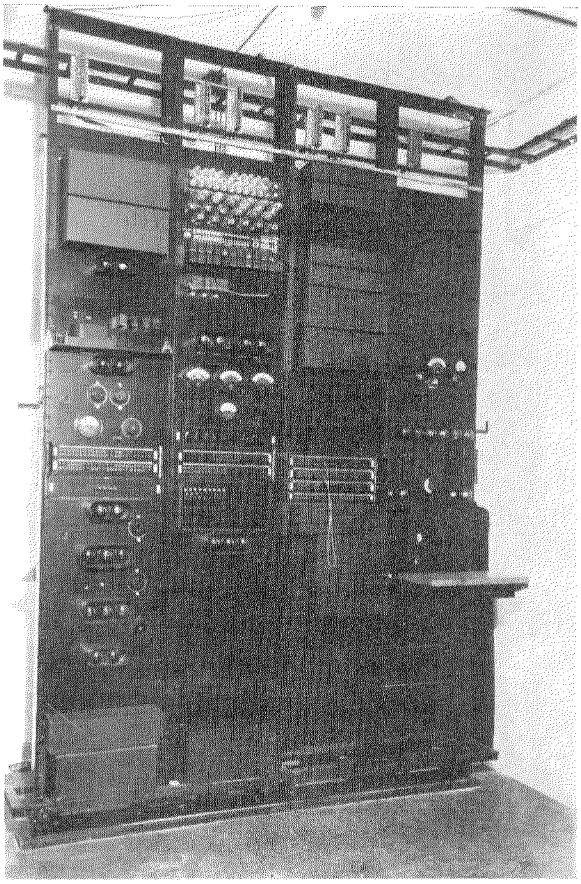

Fig. 5—Programme Carrier Terminal, Melbourne.

Fig. 4 shows the general scheme as finally planned for the initial installation. To simplify the ultimate extension of facilities the full number of six channels was provided initially on the submarine cable section of the route.

It will be observed that no use is made of the physical circuits on the land line sections of the route. These circuits were in fact already in use for purposes outside the present scheme.

Signalling Facilities

The carrier terminals at Melbourne and Launceston are equipped with the usual type of 17–1000 p : s interrupted voice-frequency ringers. In the case of the channel looped to

Currie, however, some selective ringing scheme was necessary. That adopted was as follows:

At Melbourne, this channel was equipped with two voice frequency ringers, employing frequencies of 1000 p : s and 500 p : s. On the side facing the carrier terminal (i.e., the voice frequency side) the two ringers were connected in parallel, but on the local or 17 p : s side the two ringers were led through separate pairs to jacks on the trunk switchboard, labelled " Launceston " and " Currie " respectively.

At Launceston, two ringers operating on frequencies of 1000 p : s and 750 p : s were similarly arranged.

At King Island repeater station, a 500 p : s ringer was included in the Melbourne side of the voice frequency loop to Currie, and a 750 p : s ringer in the Launceston side. On the Currie switchboard the two pairs of the loop terminate on separate jacks, labelled " Melbourne " and " Launceston," respectively, the jacks being normally connected through to each other to complete the through circuit. Thus Melbourne, for example, can ring Currie or Launceston as required by applying 17 p : s ringing current to the appropriate switchboard jack, operating either the 500 or 1000 p : s ringer. The two ringers at King Island are prevented from operating one another with 17 p : s current by the inclusion of a 100 p : s high pass filter between the switchboard jacks at Currie.

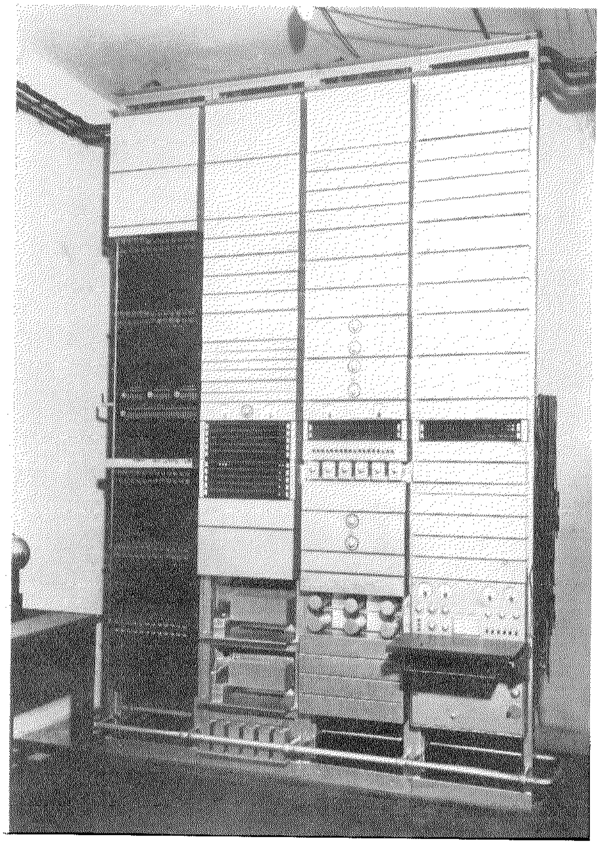

Fig. 6—V.F. Telegraph Terminal, Melbourne.

In order to provide suitable communication facilities between all stations along the route, similar ringers to those at Melbourne and Launceston were equipped at Apollo Bay and Stanley, respectively. These ringers were arranged with their voice frequency sides bridged across the physical circuit of the cable, suitable keys being arranged for ringing in either direction with the appropriate frequency. A delay circuit was used to prevent a normal short ring, such as occurs during traffic, from calling in the maintenance staff. A simple coded ring must be applied when it is desired to operate the calling devices at the repeater stations.

The ringers at Apollo Bay and Stanley were arranged so that they could be readily converted to operate as terminal ringers if it were desired to terminate the physical cable circuit at either or both of the cable terminal stations.

As the traffic on the circuits has proved to be heavier than anticipated, it has, in fact, been found desirable to employ three of the carrier channels in the cable for the through circuits, and to terminate the physical cable circuit at Stanley, the other end being temporarily extended from Apollo Bay to Melbourne via a separate single channel carrier system. For this purpose, the selective ringing equipment at Melbourne has been transferred to the single channel system.

There are at present, therefore, three through circuits from Melbourne to Launceston (one of which is in fact normally extended to Hobart by means of a single channel carrier system), and one circuit from Melbourne to Stanley, serving North-West Tasmania—this circuit being also available at Currie. As these modifications are to some extent temporary ones made as a result of traffic requirements,

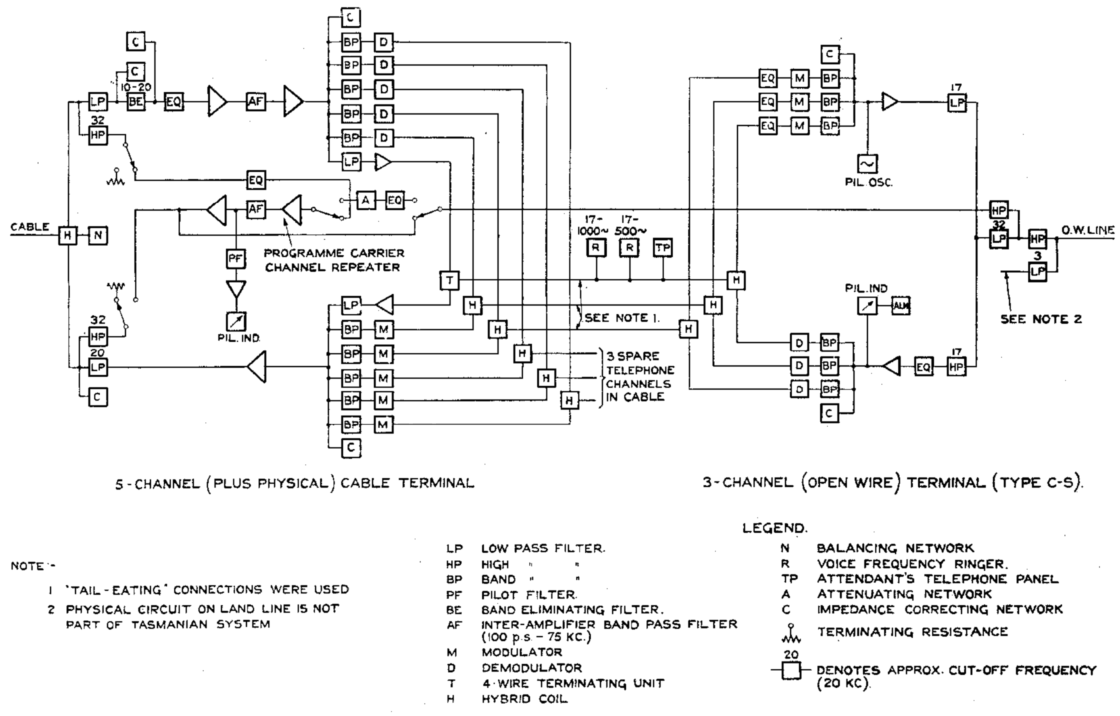
CABLE
H
N
LP
32
HP
10-20
BE
EQ
AF
C
BP
D
A
PF
PROGRAMME CARRIER CHANNEL REPEATER
PIL. IND.
20
T
M
17- 1000~
17- 500~
R
TP
SEE NOTE 1.
3 SPARE TELEPHONE CHANNELS IN CABLE
PIL. OSC.
17
3
O.W. LINE
PIL. IND.
SEE NOTE 2
5-CHANNEL (PLUS PHYSICAL) CABLE TERMINAL
3-CHANNEL (OPEN WIRE) TERMINAL (TYPE C-S).
NOTE:-
1 'TAIL-EATING' CONNECTIONS WERE USED
2 PHYSICAL CIRCUIT ON LAND LINE IS NOT PART OF TASMANIAN SYSTEM
LEGEND.
LP LOW PASS FILTER.
HP HIGH " "
BP BAND " "
PF PILOT FILTER.
BE BAND ELIMINATING FILTER.
AF INTER-AMPLIFIER BAND PASS FILTER (100 p.s. – 75 KC.)
M MODULATOR
D DEMODULATOR
T 4-WIRE TERMINATING UNIT
H HYBRID COIL
N BALANCING NETWORK
R VOICE FREQUENCY RINGER.
TP ATTENDANT'S TELEPHONE PANEL
A ATTENUATING NETWORK
C IMPEDANCE CORRECTING NETWORK
TERMINATING RESISTANCE
20
DENOTES APPROX. CUT-OFF FREQUENCY (20 KC).

Fig. 7—Block Schematic—Stanley.

and may be subject to further change as circumstances demand, no further reference is made to them and the description is restricted to the system as originally planned.

Extension of Telegraph Channels from Launceston to Hobart

The number of telegraph channels to be extended to Hobart was not considered sufficiently large to warrant the use of voice frequency operation, and it was decided to obtain these channels by means of composite circuits derived from an existing physical telephone circuit. The actual line used, as indicated in Fig. 4, is the same as that employed for the programme carrier channel.

LAND LINE EQUIPMENT

3-Channel Systems

Except for minor modifications, the two type C-S three-channel carrier telephone systems are of standard design. Each system is supplied with pilot channel equipment for its own particular section of the route in order to facilitate the maintenance of a suitable transmission equivalent under varying weather conditions.

As the attenuation of the submarine cable is not liable to short period changes, no pilot equipment was considered necessary over this section.

Programme Carrier System

This system is similar to that described in an earlier issue of *Electrical Communication.*[2] Briefly, it is a single-sideband suppressed-carrier system, employing the lower sideband of a carrier frequency of 42.5 kc. A feature of the system is that a pilot frequency of four-fifths of the carrier frequency, i.e., 34 kc., is employed not only to indicate changes in transmission equivalent but also to maintain synchronism between the carrier frequency oscillators at the transmitting and receiving stations.

The equipment at Launceston is capable of operating either as a receiving repeater or as a terminal transmitting simultaneously in both directions, and thus provides the facilities outlined previously.

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[2] "The Standard Carrier Broadcast System," by K. G. Hodgson, F. Ralph and B. B. Jacobsen, *Electrical Communication*, January, 1935.

Fig. 5 is a view of the Melbourne Programme Carrier terminal, together with the heterodyne oscillator and volume indicator used for maintenance purposes.

Voice Frequency Telegraph Equipment

This equipment operates on any one of the channels between Melbourne and Launceston. Its design follows the general lines of the 18-channel system widely used by the British Post Office,[3] the carrier frequencies employed being odd harmonics of 60 p : s. The system used in the present scheme differs from the standard system in the following respects :

(1) In order that it shall be capable of operating on either a "grouped" or a "balanced" channel in the submarine cable, the system is arranged for operation on a two-wire basis, and employs different voice frequencies in the two directions of transmission.

The system is initially equipped for five duplex channels, but is wired for eight channels.

(2) Different methods of carrier current supply are used at Melbourne and Launceston. At Melbourne, carrier current supply is obtained in the standard manner from a multi-frequency motor-generator set operating from a 24-volt battery. The carrier frequency generator is designed to supply up to ten 18-channel systems ; and, as it is not likely that there will be a large extension of voice frequency telegraph systems at Launceston, this terminal is equipped with valve oscillators for its carrier frequency supplies.

Telegraph distortion measuring equipment is supplied at both stations.

Fig. 6 is a view of the equipment at Melbourne. The distortion measuring set is seen at the bottom of the right-hand bay. The Launceston equipment consists of two bays only.

Composite Telegraph Equipment

This equipment, accommodated on a single 10 ft. 6 in. rack at Launceston and Hobart, provides initially two duplex direct-current channels over one pair of wires with earth return. Provision is made for later extension to four duplex channels.

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[3] "A New Voice Frequency Telegraph System," by J. A. H. Lloyd, W. N. Roseway, V. J. Terry and A. W. Montgomery, *Electrical Communication*, April, 1932.

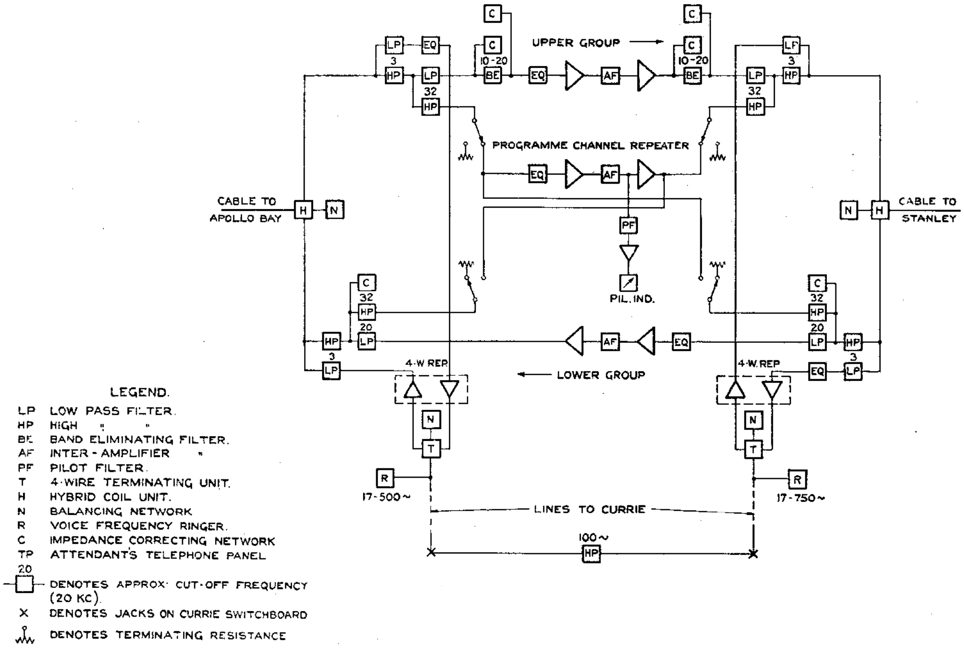
UPPER GROUP
PROGRAMME CHANNEL REPEATER
CABLE TO APOLLO BAY
CABLE TO STANLEY
LOWER GROUP
4-W REP
PIL. IND.
LINES TO CURRIE
17-500~
17-750~
100~
10-20
LEGEND.
LP LOW PASS FILTER.
HP HIGH " "
BE BAND ELIMINATING FILTER.
AF INTER - AMPLIFIER "
PF PILOT FILTER.
T 4-WIRE TERMINATING UNIT.
H HYBRID COIL UNIT.
N BALANCING NETWORK
R VOICE FREQUENCY RINGER.
C IMPEDANCE CORRECTING NETWORK
TP ATTENDANT'S TELEPHONE PANEL
20 DENOTES APPROX. CUT-OFF FREQUENCY (20 KC).
X DENOTES JACKS ON CURRIE SWITCHBOARD
DENOTES TERMINATING RESISTANCE

Fig. 8—Block Schematic—King Island.

The local circuits of the two initial channels are directly connected at Launceston to those of two of the channels of the voice frequency system, giving direct working between Melbourne and Hobart.

SUBMARINE CABLE EQUIPMENT

General Considerations

In addition to the general considerations common to all types of multi-channel carrier telephone systems, factors affecting the design of the submarine cable terminal equipment at Apollo Bay and Stanley, and the repeater equipment at King Island, included the following:

(1) The attenuation of each cable section at 42.5 kc. is of the order of 70 decibels and there are two such sections. At 31 kc. the attenuation per section is 60 db and, at 20 kc., it is approximately 50 db. The terminal and repeater gains required were therefore much higher than those necessary on land line carrier systems. It was desirable that the amplifiers used to provide these high gains should be such that their gain was not unduly susceptible to changes in battery supply voltages.

(2) The number of telephone channels contemplated, if handled by amplifiers common to all channels, called for amplifiers having considerable power handling capacity with low harmonic distortion, in order to avoid inter-channel crosstalk due to intermodulation.

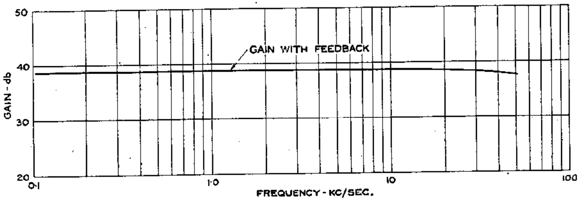

Fig. 9—Gain Frequency Curves of Reversed Feedback Amplifier.

(3) The use of a combination of balanced and grouped channels necessitated a hybrid coil unit which would carry all channels at the required power level without producing objectionable intermodulation products. The combination of the two types of channel also resulted in some complication of the directional filtering problem.

(4) The large differences between transmitted and received levels called for some care in the disposition and screening of apparatus on the bays, and in the layout of wiring between bays. Care was also necessary to prevent coupling between units via their respective battery supply circuits. The desirability of bringing these circuits in close proximity to one another for convenience in checking plate and filament currents contributed to this problem.

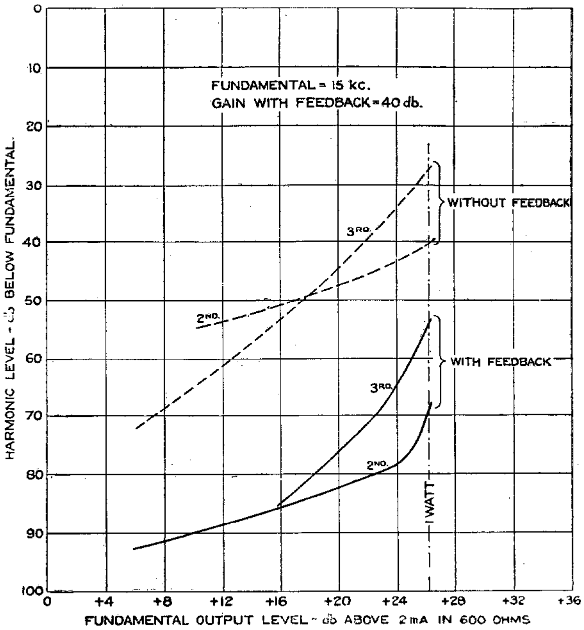

Fig. 10—Harmonic Levels in Reversed Feedback Amplifier.

(5) It was necessary to devise a suitable electrical configuration for the network used to balance the impedance of the cable and to arrange this unit in a form which was mechanically convenient for the final accurate adjustments to be made. As in all cases the cable was brought directly into the repeater station, a suitable unit on which to terminate it was required.

(6) Some form of level limiting device was necessary to prevent abnormal speech input levels on one or more channels from producing overloads and consequent crosstalk in common amplifiers. This was of particular importance in view of the use of voice frequency telegraphs on one of the channels, as interference on such channels would produce incorrect signals.

(7) The problem of designing equalisers to correct for the attenuation-frequency charac-

teristics of the cables and having a suitable latitude of adjustment for final setting in the field was one of some importance. The difficulty of forecasting exactly the attenuation of the laid cable at the lower frequencies was a factor here.

The circuits and equipment at the cable stations will now be described and discussed in relation to the above design factors.

Transmission Circuit at Stanley and Apollo Bay

The complete transmission circuit of the equipment at Stanley is shown diagrammatically in Fig. 7. That at Apollo Bay is identical except for the disposition of certain filters affected by the different frequencies employed in the two directions of transmission.

Considering this diagram first in relation to transmission on the telephone channels in the direction from land line to cable, the voice frequency band, the programme carrier channel band and the carrier telephone sidebands are first separated by two sets of high- and low-pass filters. The telephone channel sidebands then pass through the receiving side of the 3-channel C-S carrier terminal. An equaliser, common to all channels, is included to compensate for the attenuation-frequency characteristic of the line. The hybrid coils of two of the three channels are connected to similar hybrid coils of two of the channels on the cable carrier terminal. The third is connected to a four-wire terminating set associated with the physical or voice frequency channel in the cable. The connections are arranged to give what has been referred to as a "tail-eating" connection in each case. That is, the "line" and "net" sides of the hybrid coil of the C-S system are joined respectively to the "line" and "net" sides of the corresponding hybrid coil (or four-wire terminating set) of the cable system. In this manner if the "line" and "net" connections are arranged in suitable phase relationship, all the energy output of a demodulator of one system is, in the ideal case, transferred to the input circuit of the corresponding modulator of the other. This gives effectively a four-wire connection between the two channels and avoids the three decibel loss normally associated with each hybrid coil.

In the cable equipment, speech from the hybrid coils passes via modulators to band filters which select the required side-band. The cable system, like the C-S system, employs the single sideband and suppressed carrier principles, the modulators and band filters being of a similar type in both systems.

For the physical circuit, an amplifier, which is in fact half of a standard four-wire repeater panel, takes the place of a modulator, and a low-pass filter that of a band pass filter.

All channels, including the physical channel, then pass via a common transmitting amplifier to the output filter group. The transmitting amplifier is of the reversed feedback type and is described later.

Stanley is arranged to transmit the lower group of frequencies for the grouped channels, and so all the channel bands lie below approximately 20 kc. The transmitting group output filter is, therefore, a low-pass filter with a cut-off frequency of approximately 20 kc. From this filter the sidebands pass via a hybrid coil unit to the submarine cable.

In parallel with the low-pass filter is a high-pass filter, with a cut-off frequency of approximately 32 kc., through which the programme system sideband is applied to the hybrid coil when this system is operating in the direction from land-line to cable.

On the receiving side, Stanley receives the upper group of sidebands, together with the sidebands of the two balanced carrier channels and the voice frequency band.

These bands are first separated from the programme sideband by a high- and low-pass filter group having a cut-off frequency of 32 kc. The telephone channel sidebands then pass through a band-eliminating filter arranged to pass only frequencies below 10 kc. and above 20 kc. This filter, together with the 20 kc. low-pass filter on the transmitting side of the circuit, serves to provide an adequate singing margin for the station equipment. In determining the attenuation requirements for these filters, both from considerations of singing margin and possible near-end crosstalk due to modulation in the transmitting amplifier, a considerable loss across the cable hybrid coil could be assumed over the frequency range of the grouped channels, since although the hybrid coil balance does not of itself provide a sufficient margin of loss for these channels, its minimum value is nevertheless of the order of 40 decibels.

Compensating networks shown in parallel with the band eliminating network, and with the low-pass (20 kc.) filter, serve to improve the impedance-frequency characteristics of the filters over the transmission range, particularly in the neighbourhood of the cut-off frequencies. For convenience, they take the form of simple band pass filters, terminated in suitable resistances, and having pass bands which coincide with the attenuating range of the filters with which they are associated. This arrangement incidentally results in the impedance-frequency characteristic of the station, as seen from the cable, being much more uniform than would otherwise be the case, as both the transmitting and receiving sides of the equipment present a more or less uniform impedance to the hybrid coil unit at all frequencies lying in the range of the various channels.

It will be observed that the hybrid coil unit is directly adjacent to the cable and its balancing network. As a result, the hybrid coil carries all channels including the programme channel. This necessitates care in the design of the hybrid coil to avoid modulation crosstalk, but offers the great advantage that the problem of balancing a network against the cable is not complicated by the presence of filters between it and the hybrid coil. Effort in network design can, therefore, be concentrated on the reproduction of the impedance characteristic of the cable itself, without the addition of subsidiary networks to balance filters on the cable side.

From the receiving filter group, the sidebands pass through an equaliser compensating for the attenuation-frequency characteristic of the cable and then to the first of two receiving amplifiers operated in tandem. Both these amplifiers are of the reversed feedback type. As on the transmitting side, the receiving amplifiers are common to all channels, including the voice frequency channel. The sidebands are then separated and demodulated in the usual manner and the speech from three of the channels passes to the transmitting side of the land-line system. Immediately preceding each modulator of the land-line system is an equaliser. The need for this equaliser arose as follows. The complete circuit between Melbourne and Launceston consists of three carrier telephone channels in tandem. The gain-frequency characteristic of each of these channels alone is well within generally accepted limits for such channels, and is determined largely by the loss characteristic of the modulator and demodulator band filters at the terminals. When two or more such channels are connected in tandem, the overall transmission characteristic becomes progressively worse and in the present case would not have been satisfactory. The cable system by itself provided a satisfactory margin on the transmission quality limits aimed at for the system as a whole, and it was decided to equalise each channel of the land-line systems so as to make the transmission-frequency characteristics substantially flat over the required frequency range. Such equalisation could most readily be achieved at voice frequencies, and each of the equalisers shown is arranged to compensate both for the loss characteristic of the modulator band filter following it and for that of the demodulator

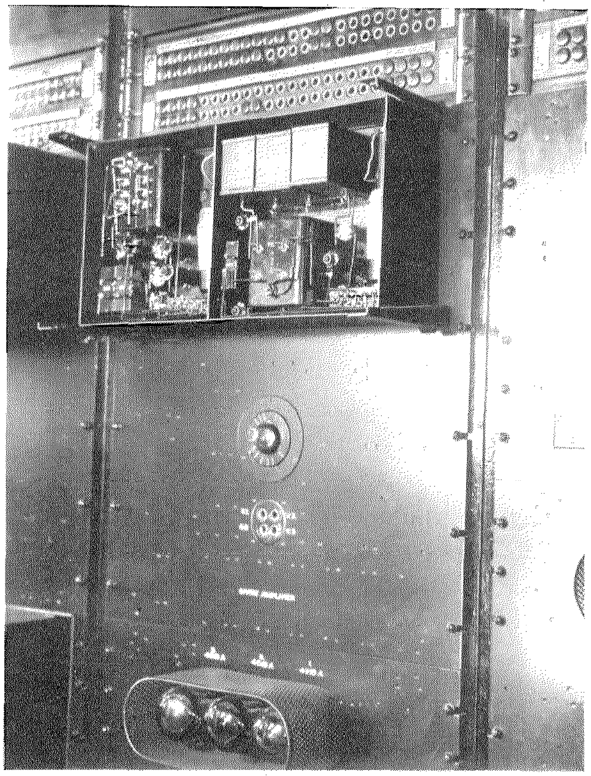

Fig. 11—Front View of Reversed Feedback Amplifier.

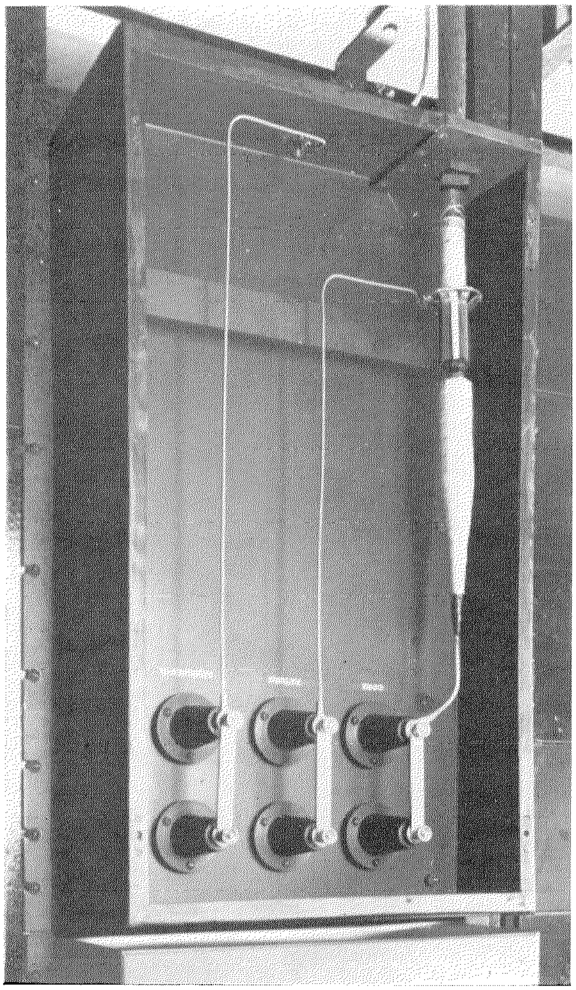

Fig. 12—Front View of Cable Terminating Unit.

band filter at the distant end. The equaliser is described in a later section. Each of the land-line terminals was fitted with equalisers, and similar units could, of course, be used on the cable equipment to obtain still greater improvement in the overall transmission characteristic, but in practice this was unnecessary.

The reversible repeater for the programme carrier channel is shown in Fig. 7, with the directional switching keys set to operate in the direction from cable to land line. From the receiving side of the hybrid coil, the sideband passes via an equaliser to the first of two amplifiers operating in tandem. These amplifiers are again of the reversed feedback type. From the second amplifier the circuit continues via high-pass filters to the land line. The method of operation in the reverse direction is clear from Fig. 7. As the attenuation of the cable is much greater than that of the land line, and the general shape of its attenuation-frequency characteristic is different, separate equalisers are used for the two directions of transmission ; the attenuating network "A" is adjusted so that the gain required is approximately the same in both directions. The pilot filter has a very narrow pass band including 34 kc., the pilot frequency. The pilot equipment shown is similar to that at a normal programme-channel repeater station, and is described in an earlier issue of *Electrical Communication* to which reference has already been made.

Transmission Circuit at King Island

The transmission circuit at King Island is shown in block schematic form in Fig. 8.

By comparison with that for Stanley, this diagram is practically self explanatory. It will be observed that the voice frequency channel is amplified separately at King Island, and that the amplification is performed in two stages. This was necessary in order to loop this channel to Currie and to control the levels in the Currie loop.

For the telephone channel repeater, two reversed-feedback amplifiers are operated in tandem, as on the receiving side at Stanley. For the programme channel the arrangements are similar to those at Stanley and Apollo Bay, except that as the two cable sections are of substantially the same length and attenuation, alternative equalisers are not necessary.

GENERAL EQUIPMENT FEATURES

Amplifiers

The amplifier requirements outlined in an earlier paragraph were met by employing amplifiers of the reversed-feedback type described in an article by H. S. Black.[4] Reference should be made to this article for a discussion of the operation of this type of amplifier. The amplifiers used in the present system are generally similar to the example described by Black. This cable system represents the first case in which reversed-feedback type amplifiers have been used in commercial practice. Only two different types of reversed feedback amplifier were employed. These both employed three valves, giving three stages of amplification, and differed only in the type of valve employed in the output stage. One type, employing a simple triode in the output stage is used as the first or input amplifier when two amplifiers are operated in tandem. The other design embodies an output valve of the coplanar grid type,[5] a feature of which is the large power output obtainable with moderate anode battery voltages. This amplifier is used as the second or output amplifier when two are operated in tandem, and also as the transmitting amplifier at the cable terminal stations. It will give single tone output of approximately one watt with a total harmonic level approximately 55 decibels below the fundamental.

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[4] "Stabilized Feedback Amplifiers," by H. S. Black, *Bell System Technical Journal*, January, 1934.

Both types of amplifier have an operating frequency range from 200 to 50,000 p : s and a maximum gain of approximately 50 db. Gain control is effected by means of a potentiometer which varies the extent of the feedback coupling, and the gain may be reduced to 30 db by this means. When lower values of gain are required attenuating pads are included in the input circuit. The gain of the amplifiers without feedback always exceeds 75 db over the above frequency range so that the reduction in gain

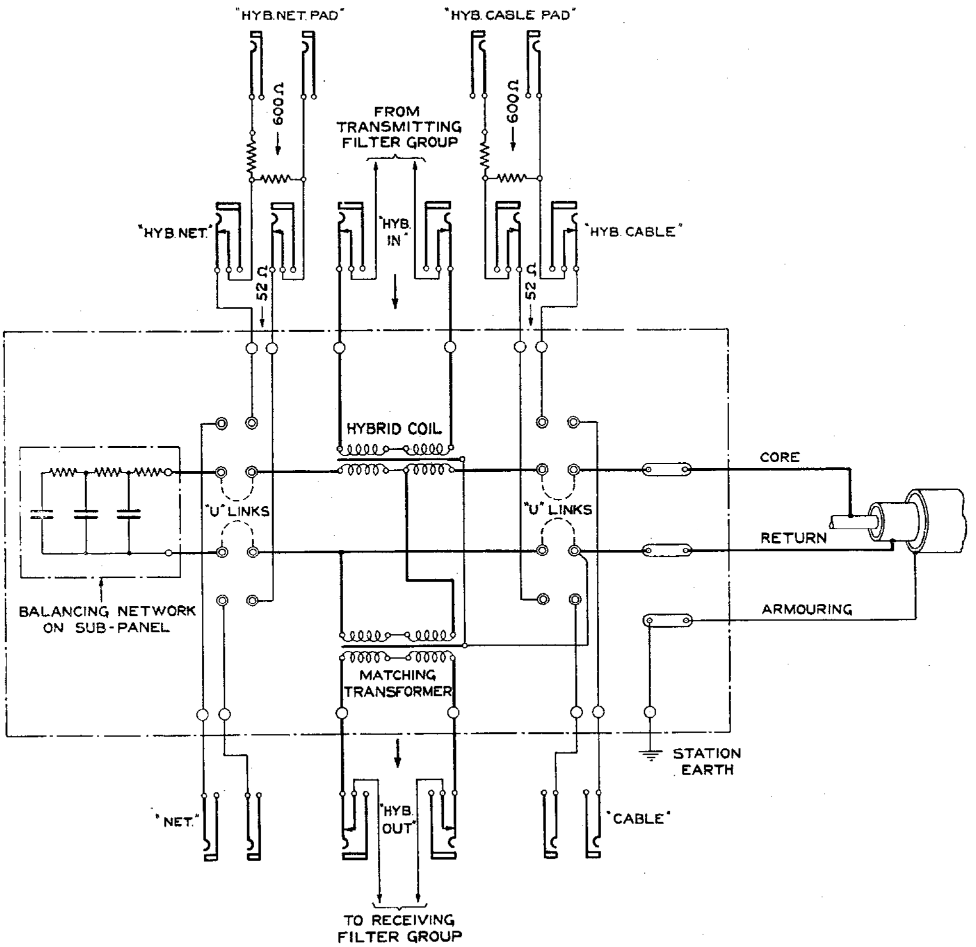

Fig. 13—Circuit of Cable Terminating Unit

due to feedback is always at least 25 db. As shown by Black, a considerable reduction in harmonic distortion and improvement in gain stability with variation in power supply voltages is therefore achieved.

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[5] "A Study of the Output Power obtained from Vacuum Tubes of Different Types," by H. A. Pidgeon and J. O. McNally, *Proceedings of the Institute of Radio Engineers*, February, 1930.

Fig. 9 shows a typical gain frequency curve, for the high level amplifier, i.e., the type employing the coplanar grid valve. The gain with feedback as shown is constant to within ± 0.6 db between 200 and 50,000 p : s.

Fig. 10 shows, for the same amplifier, the variation of second and third harmonic levels with fundamental output, with and without feedback.

Two amplifiers in tandem will give a maximum gain slightly in excess of 100 db. The maximum gain actually employed at any station is approximately 80 decibels.

It will be realised that with such high gains precautions were necessary to prevent distortion or self-oscillation due to coupling effects between input and output circuits of the various amplifiers, and between amplifiers operating in tandem.

Fig. 11 is a front view of one of the high level amplifiers with the covers removed from the screening boxes of the first two stages. The screened grid valves employed in these stages are just visible on the right of each screening box. The output valve is mounted at the rear of the panel.

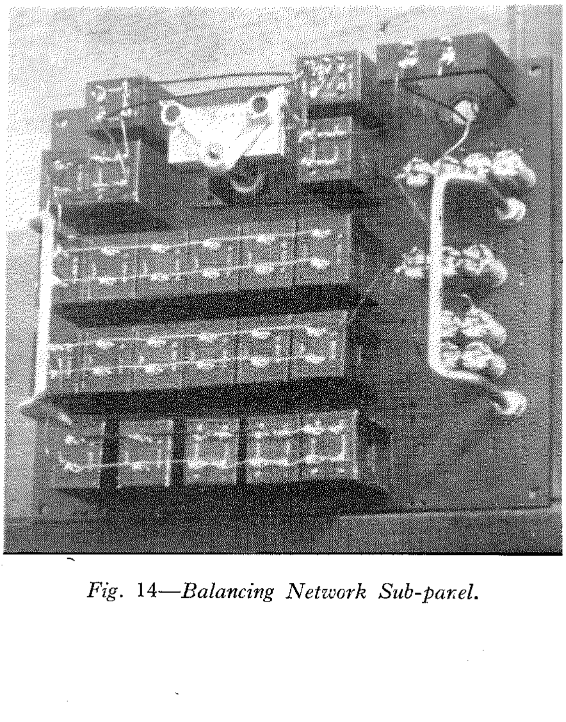

Fig. 14—Balancing Network Sub-panel.

Equalisers

All equalisers are of the constant resistance type, and in general are contained in sealed screening boxes. As the equalisation required could not be accurately predetermined, it was necessary to allow some latitude for adjustment in the field. It was found possible when designing these equalisers to obtain an adequate range of characteristics by varying only resistance components in the networks. Adjustments in the field were therefore made by strapping resistances in accordance with data collected during factory tests. The sealed cases were opened for this purpose and resealed when the final settings were obtained. In the case of equalisers for the programme carrier channel, it was known that a " straight-line " equaliser was required, but the slope was not accurately known. A number of networks of various slopes was therefore provided and the required combination of these could be selected by making connections external to the units themselves.

CABLE TERMINATING UNIT

At all cable stations, the end of the submarine cable is brought into the repeater station and joined directly to the station equipment. After a certain allowance of slack outside the station, the cable is brought up through the floor of the apparatus room and connected to terminals mounted on insulating pillars in a dustproof terminating box. From these terminals the core, return conductor, and armouring are connected via detachable links to the station circuit proper. Fig. 12 shows a front view of this terminating unit with the front cover removed.

The hybrid coil and balancing network, together with the transformer necessary to match the impedance of the terminating circuit to the impedance of 600 ohms presented by the station equipment, are mounted at the back of the unit. The complete circuit of the terminating unit is shown in Fig. 13. It will be observed that with the connections shown, the relatively high transmitting levels produce flux in the core of the hybrid coil, but not in that of the matching transformer. The core of the hybrid coil is therefore made of fairly generous dimensions to avoid intermodulation between channels.

In planning the details of the terminating unit, it was desired to make the hybrid coil, cable and network reasonably accessible for testing, but it was considered inadvisable to include jack contacts in the cable and network for this purpose owing to the danger of the balance being disturbed by faulty contacts. The arrangement shown, employing "U-links," which have generous contact surfaces and can be easily inspected, provides a convenient solution. The jacks shown are mounted on the main jack field of the bay and may be readily connected up as required for test purposes by removing the rear cover of the terminating unit and rearranging the U-links.

The jacks marked "HYB. NET PAD" and "HYB. CABLE PAD" with their associated impedance transforming resistance networks, have been found useful when making local station tests, as a 600 ohm plug serves as a network and the "HYB. CABLE PAD" jacks present the same impedance (600 ohms) as all other portions of the station equipment.

The balancing network is mounted on a separate sub-panel at the back of the terminating unit and is readily detachable for test, adjustment, or replacement by a spare in emergency.

Fig. 14 shows a view of a network sub-panel with its circuit elements strapped ready for insertion on the main panel.

Volume Limiters

The volume limiters employed on the telephone channels to prevent overload and interchannel crosstalk being caused by very loud speech are of a simple type. The primary winding of a transformer is connected in parallel with the transmission circuit at a suitable point in the voice frequency part of the circuit. This transformer has a very high step-up ratio, and across the secondary winding is connected a small neon-filled discharge lamp. The step-up ratio is so arranged that if the peaks of speech exceed a predetermined value, the lamp glows, the shunting effect produced effectively limiting the level in subsequent portions of the circuit. Although it would be imagined, at first sight, that such a device would produce serious distortion effects, tests have shown that in practice this is not the case.

Such a limiter is fitted on each channel of the three channel systems, at a point between the hybrid coil and the modulator. Limiters are also fitted in a similar position on those channels of the cable equipment which will, for the present, remain as spares, so that these channels may be extended without further attention to this problem unless demanded by the nature of the extending circuits themselves. Limiters are also arranged to be included at Currie when the circuit is interrupted at this point.

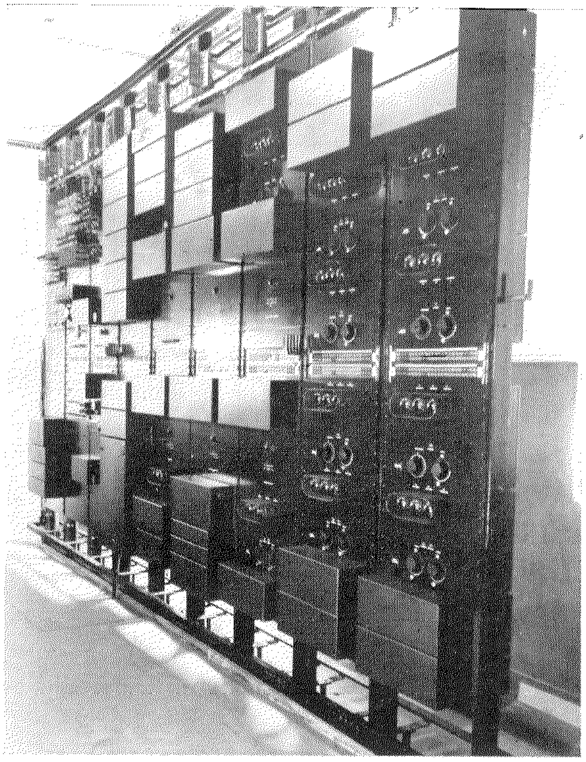

Fig. 15—Cable Equipment—Stanley.

LAYOUT OF EQUIPMENT

As in the case of the land-line equipment, the cable equipment was mounted on 10 feet 6 inch racks. Fig. 15 shows the cable equipment at Stanley, that at Apollo Bay being similar. The bays from left to right are as follows: Fuse, Battery Supply, Ringer, Cable Terminating, Carrier Programme Repeater, Receiving Amplifier and Voice Channel, Transmitting Amplifier and Channel 6, and two channel bays carrying modulators, demodulators, etc. for channels 2 and 3, and 4 and 5, respectively.

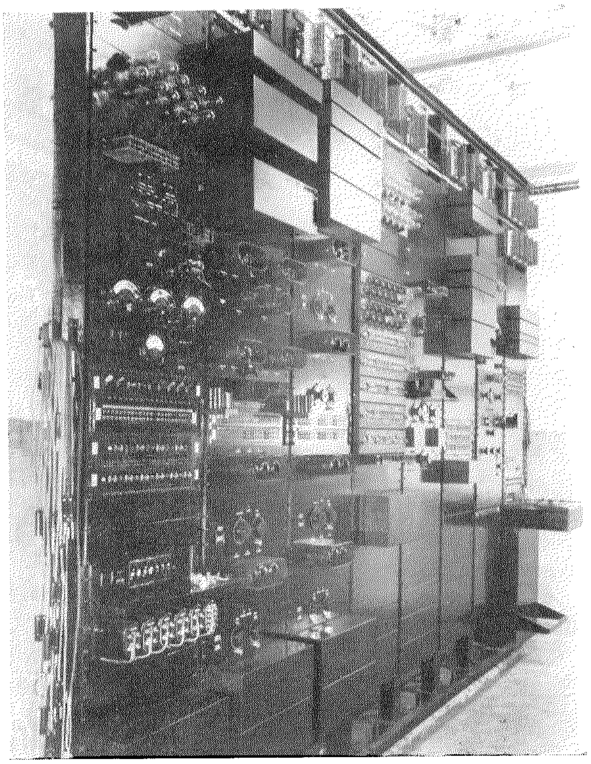

Fig. 16—*Land Line Equipment—Stanley.*

The cable may be seen coming up through the floor to the terminating unit.

Bay and interbay wiring largely followed standard carrier practice, jacks being included in the circuit to make most panels accessible for test purposes. Shielded twisted pair was widely used, and in many cases the sleeves of testing jacks were earthed to the shields of the leads to these jacks, so that, by using shielded cords for test purposes, continuity of earthing connections was ensured and undesirable looping of earth connections was avoided. Gain and loss measuring equipment employing a thermocouple was provided on the battery supply bay. With this equipment gains up to 100 decibels at 40 kc. could be measured with sufficient accuracy for field purposes.

The land line equipment at Apollo Bay and Stanley was mounted in a line facing the cable equipment, and is shown in Fig. 16.

At King Island the bays were mounted in a single line, the two terminating bays being kept as far apart as a logical circuit layout would permit. The equipment at King Island consisted of nine bays as follows : Battery supply and fuse ; Cable terminating (Apollo Bay side) ; Amplifier A to B ; Voice frequency and ringer ; Carrier programme ; Amplifier B to A ; Cable terminating (Stanley side) ; Test oscillator ; Trunk test board.

At each cable station a spare reversed feedback amplifier is provided. This is of the high output level type, and as it covers the frequency range of all channels (200 p : s to 50 kc.) it may be substituted for any amplifier in the system including, at Apollo Bay and Stanley, the three-channel system.

TESTING EQUIPMENT

In addition to a testing circuit for gain and loss measurements, the following testing equipment is provided at each of the cable stations.

Variable Frequency Oscillator

This, with its associated amplifier, will give an output of 240 milliwatts at frequencies from 35 p : s to 50 kc.

Volume Indicator

This is a 2-stage instrument and will record over a range from minus 25 db to plus 25 db referred to a zero of 6 milliwatts.

Impedance Bridge and Detector Amplifier

The impedance bridge is intended primarily for measurements on the cable and balancing network, but is also applicable to some extent to general measurements. The bridge has inductive ratio arms, and the unknown is measured in terms of a capacity in parallel with a resistance.

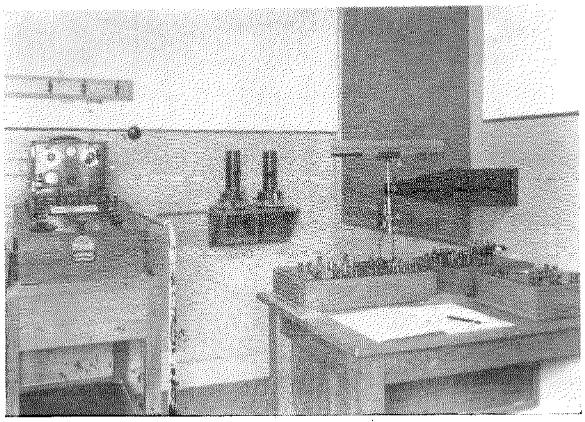

Fig. 17—*Cable Test Set and Impedance Bridge.*

As a detector for use with the bridge, the detector amplifier is used. This operates as a tuned amplifier from 200 p : s to 3000 p : s and as a heterodyne-detector from 3 kc. to 50 kc. It has a gain of the order of 60 db. Either headphones or a visual indicator in the form of a rectifier meter may be employed as the final indicating device.

The bridge and detector amplifier are mounted together on a portable test-waggon. Battery supply for the detector amplifier is obtained via cords and plugs from jacks located in a number of positions in the jack fields of the apparatus bays. The complete unit is shown on the left of Fig. 17.

Cable Test Sets

As the three cable stations were new, it was necessary to equip them with sets for making the usual direct current tests on submarine cables, and for localising any faults which might develop.

The equipment supplied is shown on the right in Fig. 17. The conductor resistance set incorporates a Wheatstone bridge of normal design with battery reversing key, galvanometer shunt and key, all mounted as one unit. A separate resistance box is supplied for use in overlap tests and for other purposes, and a two range milliammeter is included to enable the testing current to be measured when required.

Owing to the high dielectric resistance of the cables (between 500 and 1000 megohms for the whole cable) the dielectric resistance testing set had to include some special shielding features, as otherwise surface leakage would have rendered the cable tests very inaccurate. For the same reason the use of any form of combined set enabling the conductor and dielectric resistance to be obtained with the same equipment, was deemed inadvisable, as the inevitable wiring complication would have increased the surface leakage. The dielectric resistance set includes a Rymer-Jones battery reversing key, galvanometer shunt and key and a standard condenser and high resistance.

Separate galvanometers are used for the two sets as the sensitive type necessary for the insulation tests would be unsuitable for use with the Wheatstone bridge.

Testing current is obtained from large dry batteries with suitable tappings, and the galvanometer lamp is lighted from the 24 volt supply.

The sets are mounted on a suitable table with a cupboard for the batteries and test records, etc., underneath.

The whole of this d.c. testing equipment was made by Messrs. Muirhead & Co., who have had long experience with this type of apparatus.

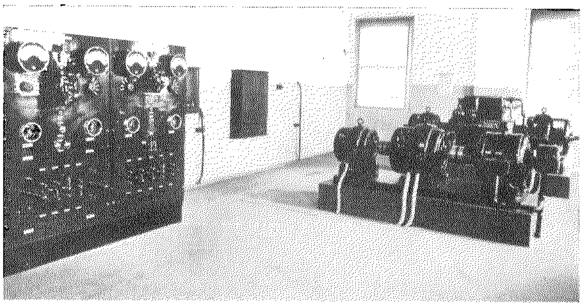

Fig. 18—Power Room—Stanley.

POWER PLANT

At Melbourne, Launceston and Hobart, all equipment is operated from existing station battery supplies. The cable stations, however, are new buildings so that complete power plant was supplied. Filament and anode supplies are provided from "Exide" storage batteries of 24 volts and 130 volts, respectively. Both batteries are duplicated at each station, and are operated on a charge-discharge basis. At Apollo Bay and King Island the 130 volt battery also serves to provide lighting for the repeater station and attendants' dwelling. At these stations, as no local power supply is available, power is provided by "Parsons" petrol engines of 20 and 8.5 B.H.P., respectively. These engines run at 1000 R.P.M. and are direct coupled to the two charging generators, one at either end of the engine, on a common bedplate. Two sets are provided at each station.

At Stanley a 415 volt slip-ring induction motor operating from the local supply drives one pair of generators, a petrol set similar to those at Apollo Bay being supplied for emergency use.

Fig. 18 shows the power room at Stanley. Fig. 19 is a general external view of the Apollo

Bay station, with the repeater building on the right. The tanks form part of the cooling systems of the petrol sets.

DESIGN OF CABLE BALANCING NETWORK

The cable balancing network is intended to present an impedance as nearly as possible equal to that presented by the cable at all frequencies in the working range, i.e., from 200 p : s to 42.5 kc./sec.

Fig. 19—General View of Apollo Bay Station.

After the cable was laid a series of measurements of its characteristic impedance had been made, in which the cable was always terminated at the far end in its characteristic impedance, the termination being adjusted for each frequency. In actual use, however, the cable is not terminated in its characteristic impedance, but in the impedance of the equipment to which it is connected. As has been explained, special measures were taken to make the impedance of the equipment as seen from the hybrid coil as nearly as practicable a pure resistance of 600 ohms, and a transformer associated with the hybrid coil was used which made the impedance of the equipment as seen from the cable about 52 ohms, this being an approximation to the high frequency impedance of the cable.

Accordingly a series of measurements was made with the cable terminated in the hybrid coil with the "HYB. IN" and "HYB. OUT" jacks (see Fig. 13) each terminated in 600 ohms. In cases where the installation had not advanced far enough for the cable to be connected to the hybrid coil, the cable was terminated in 52 ohms, and check tests later showed that there was hardly any perceptible difference between results obtained by the two methods.

The cable impedance thus measured differed from the characteristic impedance and oscillated about the characteristic impedance curve with frequency, but this oscillation could only be detected at very low frequencies; and the same smooth curve could be drawn through the measured impedance results whether they were characteristic impedances or impedances measured with the cable terminated in 52 ohms. If the network could be made to simulate the smooth curve perfectly, the maximum singing point obtainable would be determined by the deviation of the actual impedance from the smooth curve and the following statement of an extreme case will show that the procedure was satisfactory.

On the King Island-Apollo Bay cable, as measured at King Island, at a frequency of 300 p : s, the characteristic impedance and the "smooth curve" impedance both had the value 78.9–i 49.9 ohms, while that obtained with the cable terminated in the equipment at Apollo Bay was 75.84–i 51.34 ohms.

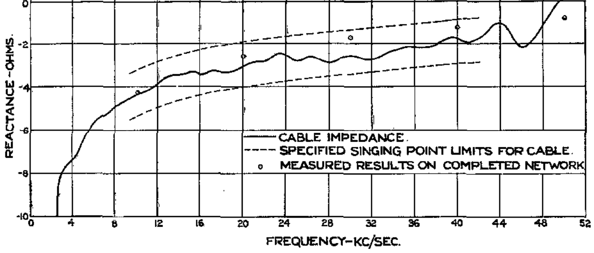

Fig. 20—Impedance of King Island–Apollo Bay Cable at King Island up to 50 kc./sec.

If the network were a perfect match to the "smooth curve" impedance, the actual singing point at this frequency would be 35 decibels, and when it is noted that the corresponding cable attenuation is only about 13 decibels, it can be seen that the margin is ample. As the frequency rose, the differences rapidly vanished and from 1000 p : s upwards they could hardly be distinguished from experimental error. At 1000 p : s the cable attenuation is 18.6 db.

Fig. 20 shows the impedance of the King Island end of the King Island-Apollo Bay cable up to 50 kc./sec. measured with the Apollo Bay end terminated in the equipment. The scale is unsuitable for showing the small impedance variations and Fig. 21 shows the portion up to 10 kc./sec. on an enlarged scale—with the smooth curve and the specified singing point limits drawn in. Fig. 22 shows the very low frequencies on an exaggerated scale to reveal the oscillation about the smooth curve referred to above.

It can be seen from Fig. 20 that at the higher frequencies the impedance approximates to a pure resistance, and owing to the fact that balanced channels were only being operated up to 9.6 kc./sec., it was evident that the networks should be primarily designed to balance the cable up to about 10 kc./sec. as accurately as possible. Previous work had suggested that the resulting network would also be satisfactory for the higher frequencies.

The type of network adopted was that shown in Fig. 23 as this form lent itself to direct computation. The previous work had shown that a six element network, as indicated, would be satisfactory. Networks with eight or more elements could have been designed if necessary, but the calculation would have taken considerably longer.

Network Results

Networks were designed for each of the four cable ends and made up on the sub-panels previously referred to, of which one is shown in Fig. 14. This sub-panel is so arranged that components can also be mounted on the back. The actual values obtained for a typical network are as follows :

$R_1=52.02$ $R_2=10.83$ $R_3=84.73$ ohms.
$C_1=2.73$ $C_2=4.39$ $C_3=7.78$ microfarads.

Considerable accuracy is necessary in adjusting the resistances and capacities, particularly in the first two sections of the network.

Fig. 24 shows the actual measured singing point curve obtained in the case corresponding to the data in Figs. 20, 21 and 22, and it can be seen that a very satisfactory margin is obtained for the balanced channels, and that the loss across the hybrid coil at the higher frequencies is still considerable.

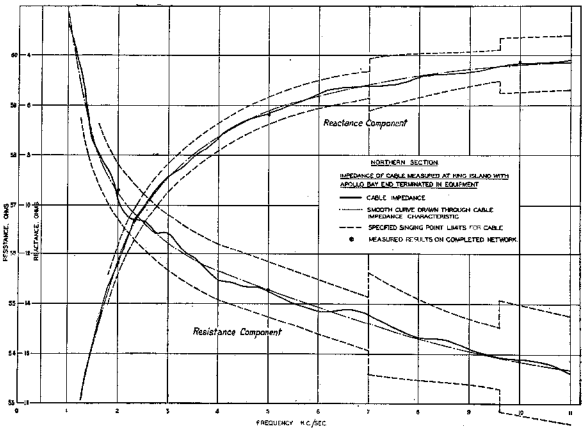

Fig. 21—Impedance of King Island–Apollo Bay Cable at King Island up to 10 kc./sec.

Fig. 24 is typical of the curves obtained in all four cases, and in general the singing point is greater than 50 decibels at all frequencies in the balanced channel range (except the very low frequencies) and greater than 40 decibels over the rest of the range.

INSTALLATION

The whole of the equipment, including power plant, was installed and wired by the staff of the Postmaster-General's Department. Some idea of the magnitude of this task may be obtained from the fact that, in addition to power plant, the equipment consisted in all of no less than seventy-four 10 feet 6 inch bays. These were distributed between the various stations as follows :

Melbourne	13	Apollo Bay	17	King Island	9
Stanley	17	Launceston	12	Hobart	6

That these were installed and wired, tested, and the telephone channels cut into service within four months of the arrival of the first bays in Australia, is an indication of the speed and efficiency with which the installation work was performed.

OVERALL RESULTS

Operating Levels

The telephone channels were required to have an overall transmission equivalent of 6

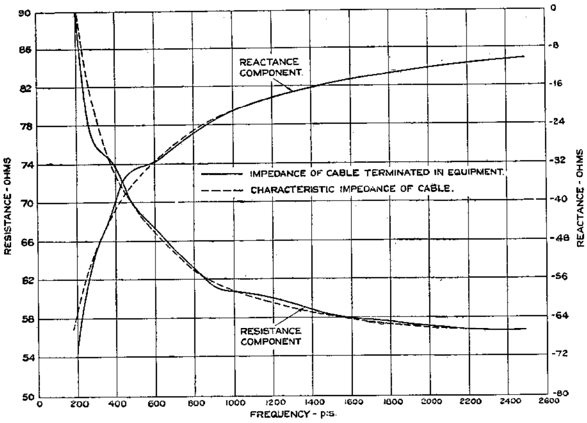

Fig. 22—Impedance of King Island–Apollo Bay Cable at King Island up to 2.5 kc./sec.

decibels at 1000 p : s. Each of the three separate carrier links was, therefore, adjusted to give a 2-wire circuit equivalent of 6 db. The use of "tail-eating" connections then eliminated 6 db loss at Apollo Bay and Stanley, giving the required overall equivalent. The approximate levels existing at each end of each cable and land-line section are indicated for the direction Melbourne-Launceston on Fig. 25. This shows the levels at the mid-band frequencies of the highest and lowest frequency carrier channels of each of the three systems, and for the physical channel in the cable. The power levels into the various line or cable sections were the same for all channels, except in the case of the physical channel at King Island, where the lower load capacity of the four-wire repeater compared with the reversed feedback amplifiers necessitated a lower output level. It is to be understood, of course, that this diagram does not represent the manner in which the various channels of the three systems were connected together.

Owing to the fact that the voice frequency equalisers before the modulators of the three channel systems correct for the distortion in the distant demodulator band filter as well as that in the local modulator filter, the levels transmitted to the land lines at the upper and lower voice frequencies are several decibels higher than those in the middle of the band.

The level diagram for the carrier programme channel is also shown in Fig. 25. It will be observed that the input levels to the two cable sections are less than those to the land line sections. This resulted from the loss in the cable hybrid coils, the levels at the output of the main amplifiers being substantially the same at all stations. Assuming these levels to be maximum R.M.S. levels in the programme transmitted, the amplifiers have a load margin of two or three decibels. The actual level of the programme into the system was controlled by observing a volume indicator. In practice it was found that over periods of several hours the average programme level was subject to considerable variations, and it was found desirable to keep the peak input level down to about 10 db below 6 milliwatts in order to avoid risk of short period overloads. As the noise level on the programme circuit was sufficiently low to permit this somewhat uneconomical use of the load capacity of the amplifiers in the system, it was in fact a convenient solution, although technically a better solution would have been provided by a close control of the level from the broadcast studio.

Transmission Quality

For the telephone channels a transmission band approximately 2500 cycles wide was aimed at on a basis of 10 decibels distortion relative to the transmission equivalent at 1000 p : s.

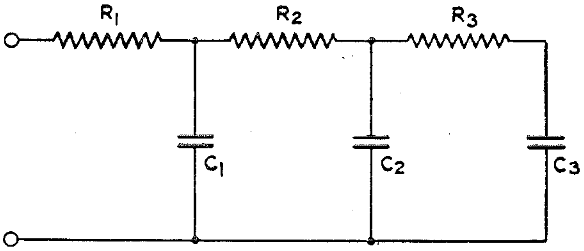

Fig. 23—Balancing Network—Form Adopted.

Fig. 26 shows a typical transmission quality curve for the complete system between Melbourne and Launceston. The corresponding curves for the constituent carrier links are also shown. The dotted curves are displaced for the sake of clarity, each link actually having been adjusted to give a transmission equivalent of approximately 6 db at 1000 p : s. It will be observed that the overall curve is substantially that of the cable link, as each of the land-line systems is equalised to give an almost flat response. As already stated, similar equalisation

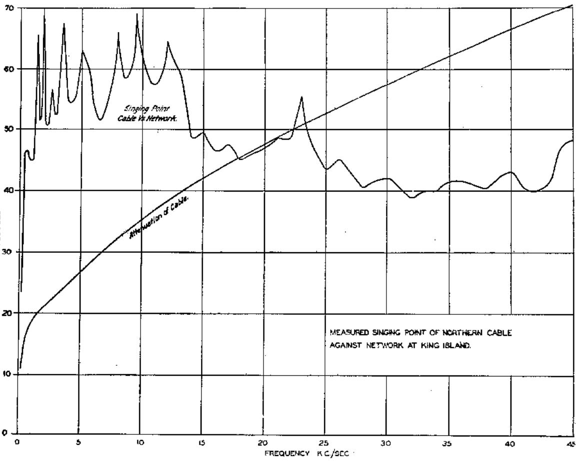

Fig. 24—Measured Singing Point Curve.

could have been applied to the cable system also if desired, but the circumstances of the present project did not warrant it.

The equaliser employed on the land-line systems is perhaps of some interest. It was of the constant resistance type, and was arranged to give a resonance peak of minimum loss at either end of the voice frequency range. Each of the resonance peak frequencies could be adjusted to a number of values by means of tapped coils and condensers, while the basic loss of the equaliser was also made variable. A wide range of adjustment was, therefore, available to allow for differences between channels. On the actual equaliser used a total of ninety different curves may be obtained, although the components occupied only one side of a mounting plate 3½ inches by 19 inches.

The overall quality characteristics of the carrier programme channel between Hobart and Melbourne are shown on Fig. 27. It is seen that the quality limits aimed at are adequately met.

Interchannel Crosstalk

With the system as a whole adjusted to operate in accordance with the level diagrams given in Fig. 25 no crosstalk between channels has been observed of sufficient magnitude to warrant the somewhat elaborate arrangements which would be necessary to measure it reliably. It will be remembered, however, that two of the channels of the cable equipment are not yet in service, so that crosstalk conditions are not severe. Laboratory measurements involving all channels do, however, suggest that all channels may be operated with the level distribution indicated in Fig. 25 without undue crosstalk. In this connection, it will be seen from the amplifier harmonic curves in Fig. 10 that in the high level amplifier harmonics remain at a very low level up to a fairly sharply defined overload point. With the aid of volume limiters, the maximum level occurring in each channel can be readily controlled so as to ensure that a safe load for the common amplifiers is not frequently exceeded.

Noise

Both the telephone channels and programme channel were remarkably free from noise. Some noise measurements were made on some of the reversed feedback amplifiers used in the cable equipment. In these tests, which were made after installation was completed, two amplifiers were arranged in tandem, separated by an inter-amplifier filter in the manner described earlier. The input terminals of the first amplifier were terminated in a suitable resistance, and both amplifiers set to maximum gain, giving a total gain of approximately 104 db. The noise output from the second amplifier was then passed through a filter passing the frequency range to be examined, and was afterwards further amplified and recorded by means of a thermocouple or a suitably calibrated rectifier instrument. The noise measured was then expressed as an equivalent input level to the first amplifier. It was found that the noise energy was uniformly distributed over the

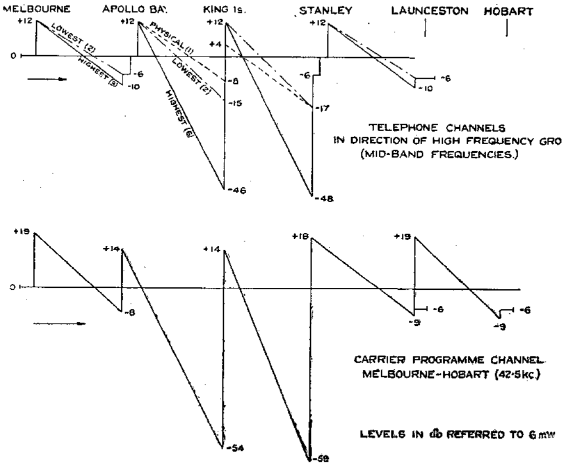

Fig. 25—Level Diagrams.

frequency scale, except that the band below 3 kc. contained somewhat more noise than a band of similar width elsewhere in the spectrum. Typical results were as shown below :

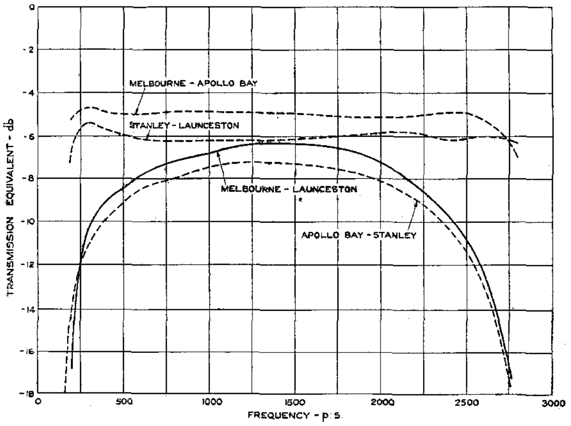

Fig. 26—Quality Curve—Telephone Channel.

Conditions.	Equivalent Input Noise Level referred to 1 milliwatt.
Noise in any 2500 p : s band between 3 and 30 kc. (measured through filter giving 5 db distortion at 2500 p : s band width)	– 128.5 db
Noise below 2900 p : s. . . .	– 126 db
Total noise below 32 kc. . .	– 116.5 db

The above figures varied approximately ± 3 db for various amplifiers.

For an input level of 6 milliwatts at the terminal station, the lowest level existing on any telephone channel at the input of an amplifier on the present system is approximately 58 db below 1 milliwatt. This occurs at King Island and at Stanley in the Melbourne-Launceston direction. In the reverse direction, the lowest level existing is 47 db below 1 milliwatt at King Island. The ratio of signal strength to amplifier noise is therefore ample. On the programme channel, for an input 10 db below 6 milliwatts, the lowest level occurring is approximately 66 db below 1 milliwatt, the levels at the three cable stations ranging from 54 to 66 db below 1 milliwatt. As the programme channel should transmit efficiently a volume range of 40 db, the above figures, for the weakest programme input, become 94 and 106 db, respectively.

It is seen from the above that the amplifier noise does not enter seriously into circuit conditions in the present system. In the case of the programme channel, however, owing to the large volume range to be reproduced, it probably would not be practicable to operate with minimum levels much lower than those existing. As already mentioned, however, close regulation of maximum transmitted level would, if this were necessary, permit the input level at the terminal station to be raised considerably above the value of 0.6 mW assumed in the above discussion, with consequent further improvement in the signal to noise ratio.

Telegraph Channels

The telegraph channels will not, for the present, be used for traffic, as existing telegraph cables to Tasmania are able to meet present requirements. For purposes of test, however, the voice frequency telegraph system was applied to one of the Melbourne-Launceston channels, the actual channel employed being one involving a balanced channel in the cable equipment. Distortion measurements made with the representative word "PARIS" at a speed of 50 bauds in either direction gave distortions averaging rather less than 10 per cent. With each channel looped at Launceston, distortion measurements from Melbourne to Launceston and back gave values up to 12 per cent.

Measurements between Melbourne and Hobart, including the composite telegraph extensions between Launceston and Hobart, gave distortions at 50 bauds up to 16 per cent.

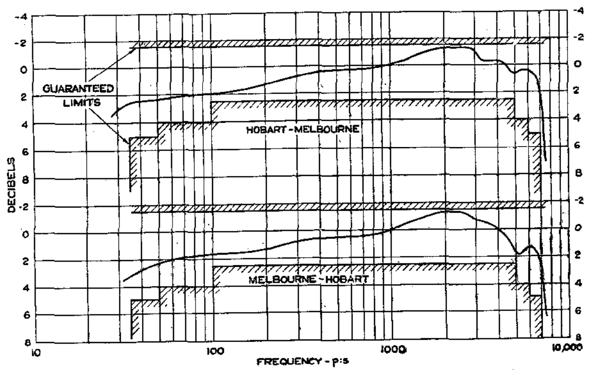

Fig. 27—Quality Curve—Programme Channel.

As the guaranteed maximum distortions on the Melbourne-Launceston and Melbourne-

Hobart channels were, respectively, 20 per cent. and 25 per cent., the results obtained were very satisfactory.

Traffic

The establishment for the first time of telephone communication between two areas having a large community of interest, each of which had already its own telephone network, gave rise to an unusual situation from the traffic point of view. It was naturally impossible to estimate accurately what the traffic density would be, and some figures may therefore be of interest.

It is the practice in the Commonwealth to base the charges for trunk calls on the air line distance between the points connected, and this principle is applied to the Tasmanian link, in spite of the heavier initial cost of establishing the circuits. The charges for the various periods of the twenty-four hours are at present as follows :

	9 a.m.– 6 p.m.	7 a.m.– 9 a.m. 6 p.m.– 9 p.m.	9 p.m.– 7 a.m.
Melbourne-Launceston	3s. 6d.	2s. 8d.	1s. 9d.
Melbourne-Hobart ..	4s. 6d.	3s. 5d.	2s. 3d.

During the first week after the service was opened, the daily average number of calls for a week-day was 313, while the corresponding figure for the first three months in service was 252 calls. As the average for the third month of service (June) was 237, it would appear that the initial rush of business arising from the novelty aspect has died out and that traffic is likely to be maintained at the high level indicated. In this connection it is of interest to note that the additional land-line systems for bringing the remainder of the cable channels into service have already been ordered.

CONCLUSION

The authors wish to express their sincere appreciation of the work of the engineering, installation and maintenance staffs of the Postmaster-General's Department throughout the work of installing and testing the equipment, and, in particular, for the spirit of willing co-operation in which that work was carried out. The authors also wish to thank the Department for permission to publish the various photographs and other data contained in the paper.

Two Kilowatt Broadcasters in Bulgaria

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A FEW years ago, in order to furnish good broadcasting service to the largest possible number of listeners, the Bulgarian Postal Administration decided to provide an up-to-date broadcasting system.

Owing to the peculiar geographical nature of the country, it was from the very outset obvious that for a satisfactory distribution of field strength more than one broadcaster would be necessary. Bulgaria extends from West to East, and by the ragged range of the Balkans the oblongly shaped country is divided into two sections. Preliminary studies showed that three stations at least would be required for an efficient broadcasting service.

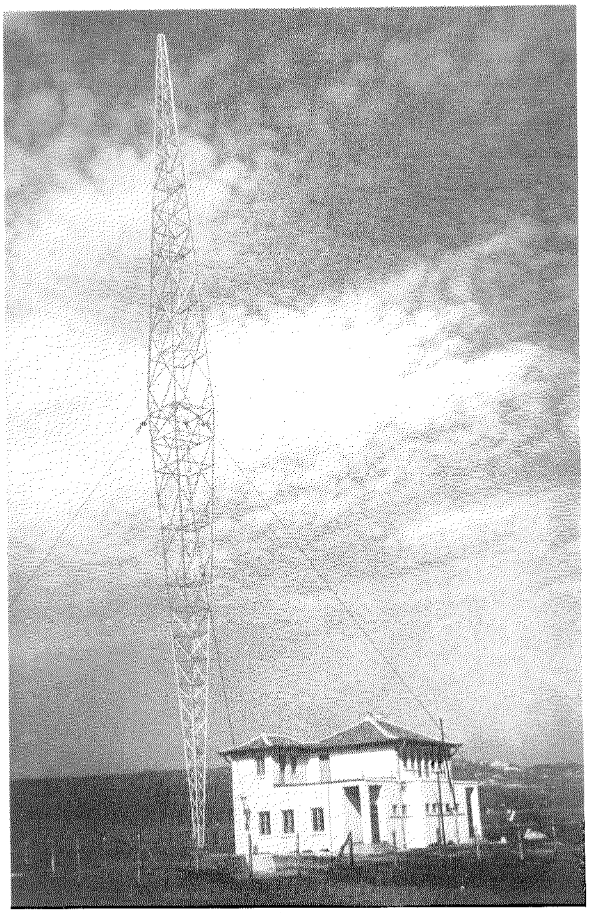

Fig. 1—Transmitter Building and Antenna at Varna.

The first stage in the execution of the programme of the Administration was the erection of two small broadcasters.

The determination of the site of these stations required much effort on the part of the Radio Department of the Administration. A portable radio transmitter was stationed at various points of the regions which, based on previous geographical studies, had been roughly chosen. The best results were obtained in the vicinity of Varna and Stara Zagora, towns which were then definitively made the sites of the two broadcasters.

At first—at the beginning of the year 1936—the station of Stara Zagora was installed. Then, in about a month and a half, Varna followed. Trial transmissions took place at both stations in April, while regular service was started in May, 1936.

Both transmitters are equipped with complete speech input equipment installed at the respective studios located in Varna and Stara Zagora.

The broadcasters, which were ordered from Standard Electric Company Ltd. (Hungary), are of the full mains operated type having an unmodulated output power of 2 kW. The wavelengths are 235.1 metres for Varna and 214.0 metres for Stara Zagora.

In this system, the carrier frequency of the transmitter is generated by means of a master oscillator at low power level. The oscillator provides the sole drive for the subsequent stages of the transmitter, and the frequencies are maintained within close limits by means of crystal control. Modulation occurs at a considerably higher level in order to prevent the carrier frequency from being affected by it.

Modulation of the carrier by the audio frequency input suitably amplified is performed in the output of the modulated amplifier stage, the anode circuits of the modulator and modulated amplifier valves being coupled by means of a transformer. To ensure high degree, distortionless modulation, the modulator stage has a relatively large power handling capacity. All amplifiers use balanced push-pull circuits. This system practically eliminates reaction and thus secures a straight line characteristic for the amplifiers; it also renders the tuning of the various circuits mutually independent.

The transmitters are about six to seven kilometres distant from the two towns. For the transmitting buildings, separate three-phase 6000-volt transmission lines are required. The voltage is transformed into 380 volts 3-phase; and, on account of the frequent voltage fluctuations in the mains, this secondary voltage is stabilised by a rotary voltage regulator.

The transmitter building and antenna at Varna as well as the general layout are shown in Figs. 1 and 2. The latter represents the plan view of the ground floor in which the transmitter and all power supplies are installed.

The 6000/380-volt 3-phase transformer is in room "T" of the figure. The secondary voltage is stabilised by the rotary regulator in room "R."

All radio frequency and power supply equipment is installed in the large central hall. At the left is the line amplifier and by its side, a little to the rear, the high frequency stability master oscillator. From left to right are: the low voltage rectifier, the oscillator-modulator unit and the power amplifier. The high voltage rectifier is located on the right side.

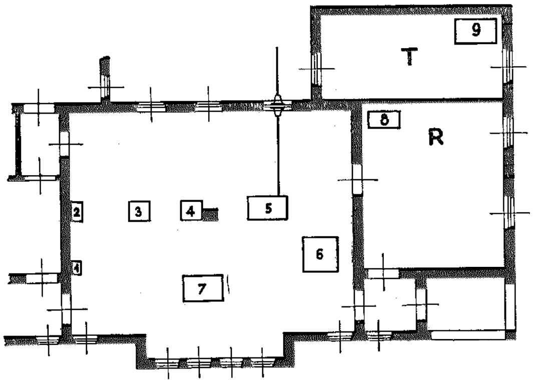

Fig. 2—Plan of Ground Floor Layout, Varna.

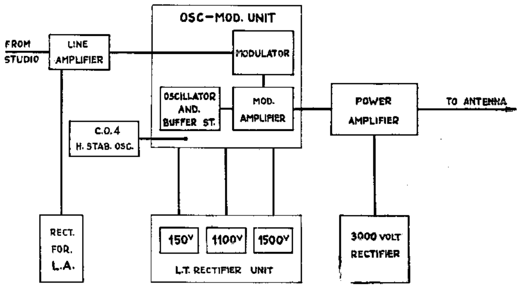

Fig. 3—Transmitter Circuit, Block Schematic.

Press buttons for start and stop and monitoring jacks are mounted on the desk situated in the middle of the transmitting hall.

The transmitting buildings and the city studios are connected by two 2-wire open wire lines. The line amplifier, to which one of the lines is connected, is provided with a volume indicator. By means of the volume indicator the incoming transmission level is checked daily, and thus it is possible to free the level from temporary fluctuations of the attenuation of the open wire line.

The maximum amplification of the line amplifier is 45 decibels; its frequency characteristic is adjusted so as to equalise the distortion of the open wire line.

The output of the line amplifier is connected to the two-stage modulator, the first stage of which incorporates two 50-watt, the second stage two 250-watt valves.

The outgoing circuit of the modulator is connected in series with the anode circuit of the modulated amplifier. The Heising method of modulation is employed.

The input circuit of the modulated amplifier is fed by the type C0.4 master oscillator, which produces the carrier frequency of the transmitter with a stability of 5×10^{-6}. For stabilisation a quartz crystal is used. The crystal is mounted in a special thermostat

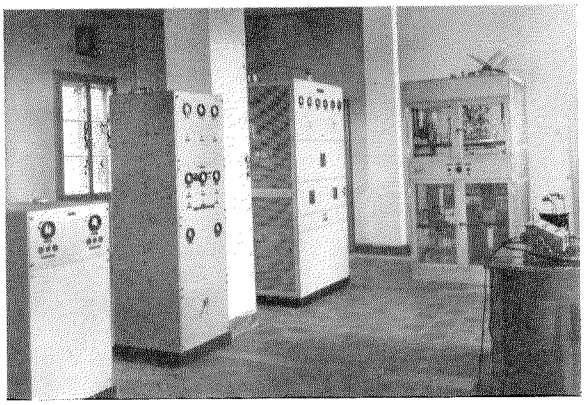

Fig. 4—Transmitter Room at Varna. From left to right: Low Voltage Rectifier, Oscillator-Modulator Unit, Power Amplifier and High Voltage Rectifier.

with a temperature variation of not more than 0.1° Centigrade.

There is another, a spare crystal oscillator installed in the oscillator-modulator unit. The frequency stability of this unit is 25×10^{-6}.

The 250–watt modulated amplifier drives the power amplifier stage, which consists of four parallel and push-pull connected 1.2 kW. air-cooled valves with the necessary output and antenna tuning circuits.

Power supply equipment consists of rectifiers exclusively; no rotating generators or storage batteries are used.

The following voltages are produced by the low voltage rectifier by means of hot cathode mercury vapour rectifier valves:

150 volts grid for the various units,
1100 volts anode for the oscillator, modulated amplifier and the first stage of the modulator,
1500 volts anode for the second stage of the modulator.

The 1.2 kW. valves are heated by 10 volts a.c. The necessary grid bias is supplied by a dry rectifier installed in the unit itself.

The 3000-volt anode voltage of the power amplifier valves is supplied by a 3/6–phase grid controlled mercury vapour rectifier with glass bulb. This rectifier is placed in the unit itself together with all auxiliary circuits. The mercury vapour rectifier is ignited automatically.

The transmitter (Figs. 3, 4 and 5) is centrally controlled by three press buttons mounted on the monitoring desk. With the aid of a remote control circuit, the station may also be started or stopped from the studio in the city. Alarms inserted in the starting circuit signal failure of both antenna and mains current.

An interval of less than a minute is required for starting the complete transmitting equipment. The proper sequence of switching is safeguarded by a set of automatic delay relays. All voltages and currents may be read on meters on the front panels of the units.

Removable turn-dials serve for tuning in and adjusting the transmitting equipment.

Adequate protection is provided both for personnel and apparatus. The apparatus is assembled in totally enclosed units with "dead" front panels. Access to apparatus in the various units is obtained through a door at the rear of each unit. The doors are fitted with safety switches which ensure that all high tension supplies are removed from the units before the doors are opened.

To protect the valves and other expensive pieces of apparatus from damage due to faulty operation, the switching arrangements are such as to prevent the various voltages from being applied in the wrong order, and provision is made for the automatic disconnection of the high tension supplies in the event of failure of the grid supplies.

The equipment is characterised by safety, simplicity and ease of operation.

The antenna is at a distance of about fifteen metres from the transmitting building. A simple transmission line connects the two.

The excellent quality of the transmitter is best shown by a few data from the Minutes

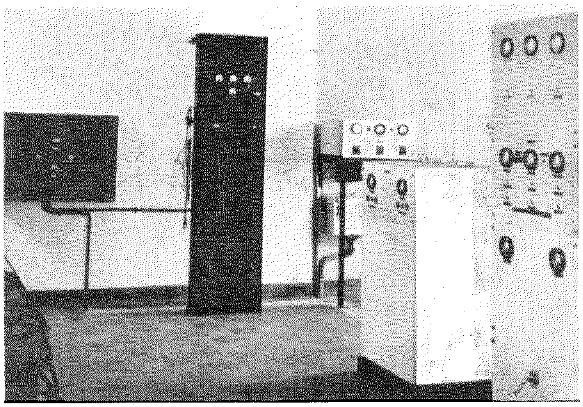

Fig. 5—Transmitter Room at Varna—Line Amplifier and High Stability Master Oscillator.

taken on the occasion of the acceptance tests. For Varna, the following data were obtained :

Output Power : The unmodulated radio frequency output was 2.07 kW.

*Klirr factor :** (measured at 400 p : s)

Modulation per cent.	*Klirr Factor per cent.*
70	2.99
80	3.70
90	4.56
100	7.31

Audio frequency characteristic (measured between 35 and 10,000 p : s) : The maximum variation was 1.66 db.

Carrier noise :
55 decibels, below the level of 100 per cent. modulation.

Power consumption :
When unmodulated, 11.15 kW.

Efficiency : 18.5 per cent.

Acceptance tests were made with the very accurate General Radio Monitoring Assembly, with due regard to all corrections.

The speech input equipment (Fig. 6) installed at the studio in the city is also of the entirely mains operated type. It is provided with three pre-amplifiers for the moving coil microphones.

A four-channel mixer panel is used for mixing the different microphones or other pick-up circuits. By means of the main amplifier, the level is raised to the suitable value.

In this system, the total gain between microphone and line is divided into two parts. The pre-amplifier used between microphone and mixer has a gain of about 20 decibels. After the mixer, the main amplifier follows with a maximum gain of about 60 decibels, giving—for normal modulation—an average of 1.2 volts to the 600-ohm transmission line.

The design of the jack strip of the amplifier equipment allows of transmission of various broadcast plays. As switchings must be performed in logical order, errors are almost entirely excluded. The circuits of three microphones and of a gramophone may be mixed in all possible combinations ; and, in addition, outside broadcast facilities have been provided for. The incoming and outgoing lines are connected through a separate jack strip.

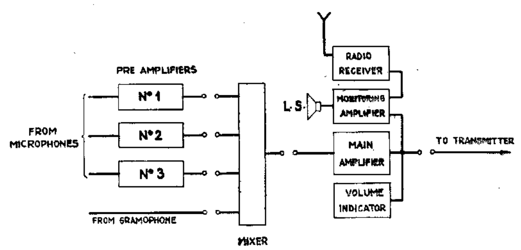

Fig. 6—Speech Input Circuit in Studio—Block Schematic.

Special attention was given to the elimination of noise due to mechanical and acoustical shocks to the valves.

Standard moving coil microphones are used. This type is most suitable for both studio and outside broadcasts.

A volume indicator connected to the output circuit of the main amplifier has been provided for adequate control of the programmes. This indicator, which shows the average value of the programme level, is of the low speed type.

Transmissions of programmes may be listened to with headphones or through the monitoring amplifier by means of a loud speaker. The radiated programme is received with an inbuilt receiver ; and, by means of a key mounted on the monitoring amplifier, the reception may be checked against the actual transmission.

The excellent quality of the speech input equipment is indicated by the following data taken from the Minutes of the acceptance tests for Varna :

Frequency response characteristics between 30 and 10,000 p : s. Maximum variations measured :

(*a*) Three pre-amplifiers : 0.86, 1.06 and 1.06 db.

(*b*) Main Amplifier : 1.9 db.

(*c*) Line Amplifier : (at the transmitter) 1.0 db.

Klirr factor (measured at 400 p : s) :
Line Amplifier : 0.8 per cent.

No measurements have as yet been taken of the radiating quality of the transmitters. However, good quality broadcasts, for example, are received from Stara Zagora even several hundred kilometres beyond the frontiers of the country, such as in Budapest and in Alexandria.

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* Coefficient of non-linear distortion.

History and Application of Piezoelectricity

By M. TOURNIER,

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NATURE, which endowed man with the power of doing mechanical work with his muscles, did not furnish him with an obvious means of producing electricity. It was only in the 17th Century that Volta, by inventing the battery, gave humanity the first source of electrical energy.

After Faraday and Ampère, engineers learned to devise machines for transforming energy for distribution in electrical form. In these machines, iron or magnets were always found; and ferro-magnetism, that mysterious molecular property of iron, has been basic in the development of the electrical arts: it is the transformation medium between electrical and mechanical energy. For about half a century, this link between matter and electricity seemed unique and irreplaceable.

Then came the notable studies of Becquerel and Gauguin on pyroelectricity. The theories formulated by the Curie brothers to explain this strange phenomenon led them to foresee a new property of matter: piezoelectricity, the specific attribute of certain crystalline substances. Langevin showed subsequently that piezoelectricity made it possible to create a new branch of electro-technique whereby the exchange of mechanical and electrical energy may take place in both directions without the intervention of ferro-magnetism. Quartz made its entry in this technique; and in a very few years, a large number of applications were developed, thanks to the work of Curie and Langevin.

History of Piezoelectricity

Piezoelectricity is the property of electrical polarization possessed by certain crystals when subjected to mechanical deformation. The kindred phenomenon, pyroelectricity (the polarization of certain crystals when heated), had been known for a long while. In the *Annals of Chemistry and Physics* there exists a paper of Becquerel on this subject dating from 1828, and an important paper of Gauguin in 1856.

In 1881, Pierre Curie studied pyroelectricity and gave an interpretation of it deduced from theoretical and philosophical considerations. The development of these theories led him to foresee, before he was really able to observe it, the new phenomenon—piezoelectricity. In the history of science, this discovery is one of the rare examples of a new physical fact which was of capital importance for the future of scientific research and which was completely foreseen before it was found by experiment.

The discovery of the planet Neptune has been largely quoted and admired for the efficiency of the Cartesian method of reasoning. It is well known that after observing the perturbations of Uranus, Le Verrier foresaw the existence of a planet, until then unknown, for which he published the constants and coordinates. Galle, a German astronomer, discovered it at the appointed hour in that part of the sky which Le Verrier had indicated. Almost at the same time, Adam, an English astronomer, who was not aware of these studies, announced the existence of this planet in the same place and by almost the same calculations. Such facts illustrate the power of the scientific method created by Descartes and developed and formulated by Claude Bernard, the operations taking place in the following order: observation, hypothesis, and experiment, contradicting or corroborating the hypothesis.

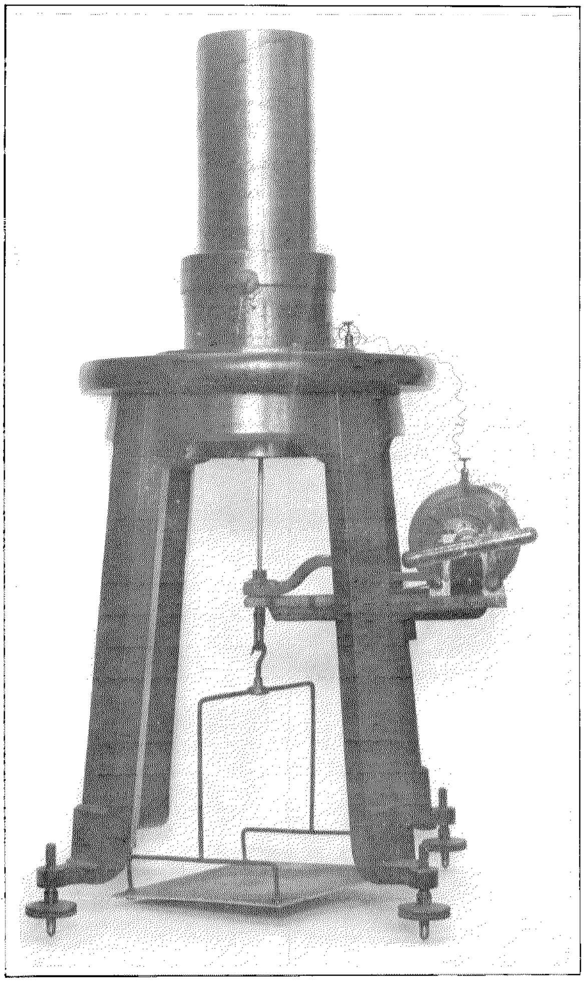
In the discovery of piezoelectricity, we again find these three stages. Here the analysis of facts by the scholar's mind is singularly original and powerful. After crystallographic studies, Curie enunciated the principle of symmetry, which may be summarized as follows:

When a phenomenon A, which presents special characteristics of symmetry is the cause of a phenomenon B, we find, in the symmetrical elements of B, those which are the special characteristics of A. Conversely, if we observe in a phenomenon "effect" B special characteristics of symmetry, we may be sure that they exist also in the "cause" phenomenon A.

Example

The magnetic field has a symmetrical character completely represented by the properties of an axial vector. A mass of iron placed in an electro-magnetic field becomes magnetized. This effect can be represented and measured by the knowledge in each point of the solid of the magnetizing vector, which is, itself, also an axial vector.

The application of a force (symmetry of a polar vector) to a free material mass produces an acceleration of this mass. The acceleration also has the symmetry of a polar vector.

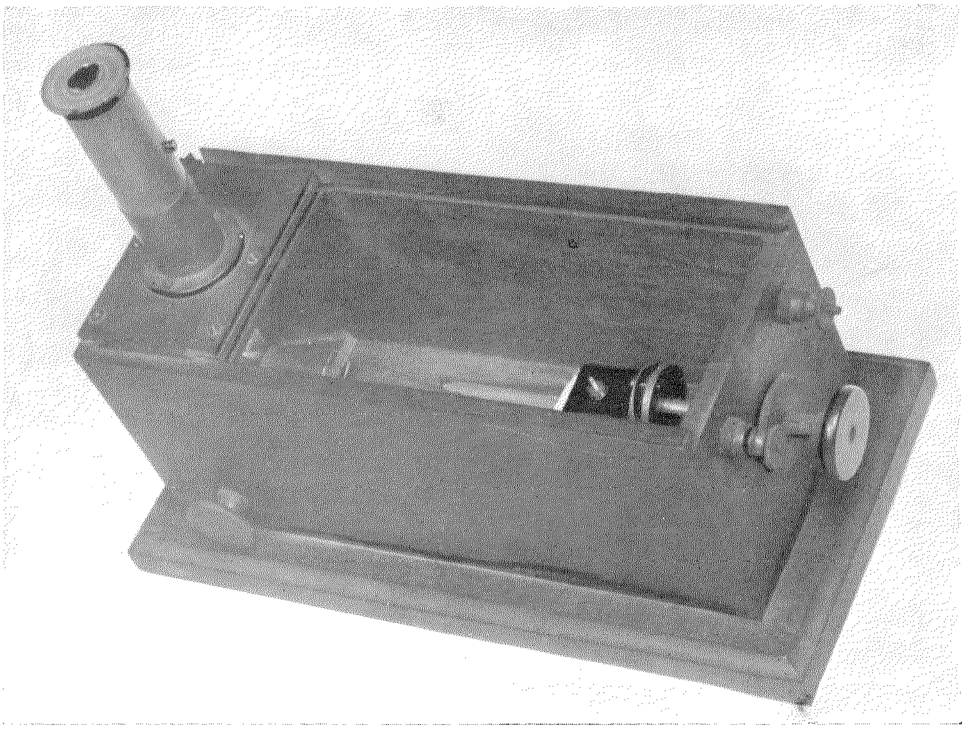


Curie "Piezoelectric Quartz" Apparatus.

The electric field has the symmetry of a polar vector. When one places in it a dielectric substance, this polarizes itself electrically. The electrical polarization vector, which permits the representation of this modification of the space property, also possesses the symmetry of a polarization vector.

Pyroelectricity seemed to have escaped this law. The apparent cause of the elevation of temperature phenomenon may be represented by a scalar quantity. The "effect" phenomenon, which is here the electrical polarization, should be represented by a polarization vector. The principle of symmetry seems to be at fault. Curie remarked that pyroelectricity is not a general phenomenon and that it is only observed in certain crystals endowed with special elastic properties. The symmetrical type, which it is impossible to discover in the initial physical agent, must exist in the crystal.

The action of heat in the crystal determines the tensions distributed in space by reason of its elastic properties. When these tensions are distributed in space with the symmetry of a polar vector, the substance may be pyroelectric. Such is the case of the hemimorphic hemiedrie of the tennary system (tourmaline), of the hemimorphic hemiedrie of the orthorhombic system (calamine, resorcine), and of the enantiomorphic hemiedrie of the clinorhombic system (sugar, tartaric acid, tartrate of potash). The action of an exterior force also determines the appearance of tensions in an elastic and unisotropic substance. When the elastic properties of the substance are such that the application of an exterior force determines the internal tensions regulated according to the character of the symmetry of the electrical field vector, polarization may appear. It is, obviously, impossible to apply a single force to an isolated substance. One can only imagine that the substance is submitted to two equal and opposing forces (the pressure of a clamp) between which one cannot distinguish a predetermined direction. In order that these opposing forces may produce an effect which can be represented by a single vector with fixed orientation, the crystalline substance must be deprived of its center of symmetry. Among the twenty-one classes of crystals deprived of this center, we find twenty which are piezoelectric. These facts, enunciated by Curie in



Curie Electrometer.

several papers, were experimentally verified by him, but his principal study was made on quartz. The laws of Curie are the following: First law: Whatever be the direction of the pressure applied to the crystal, the polarization is always normal to the optical axis; Second law: A uniform pressure parallel to the optical axis does not produce polarization; Third law: The charge dQ is proportional to the force dF when the latter is directed according to the electrical axis, that is,

$$dQ = KdF.$$

When the force dF is applied in a perpendicular direction to the electrical and the optical axes, the quantity of electricity liberated on the electrode is $dQ = K(L/e)dF$. The first equation must be completed by the consideration that the charge may be modified by variation of the potential imposed on the electrode. In other words, for a condenser of piezoelectric dielectric, the charge is the function of two independent variants, the applied force F and the potential V. The final equation is, therefore:

$$dQ = KdF + CdV \quad \text{(Curie's equation)},$$

where C represents the electrostatic capacity of the condenser of constant force.

Curie was interested in electrometrics as well as in crystallography, and he thought of utilizing the property of quartz, which he had just discovered, to evaluate electric quantities in terms of force.

In collaboration with his brother, Jacques Curie, he constructed the apparatus known under the name of "Piezoelectric Quartz." In this apparatus, a sheet of quartz cut perpendicularly to the electrical axis is fixed between two jaws; the upper jaw is fixed to a rigid support, the lower to a scale which permits the application of a force by means of a known weight. The direction of the force is perpendicular to the optical and electrical axes.

The sheet is covered with tin for receiving the charges. One of the tin sheets is connected to ground, the other to an insulated pair of quadrants of an electrometer mounted heterostatically. The sheets are dimensioned so that one kilogramme of traction corresponds to an absolute C.G.S. electrostatic unit of electrical quantity.

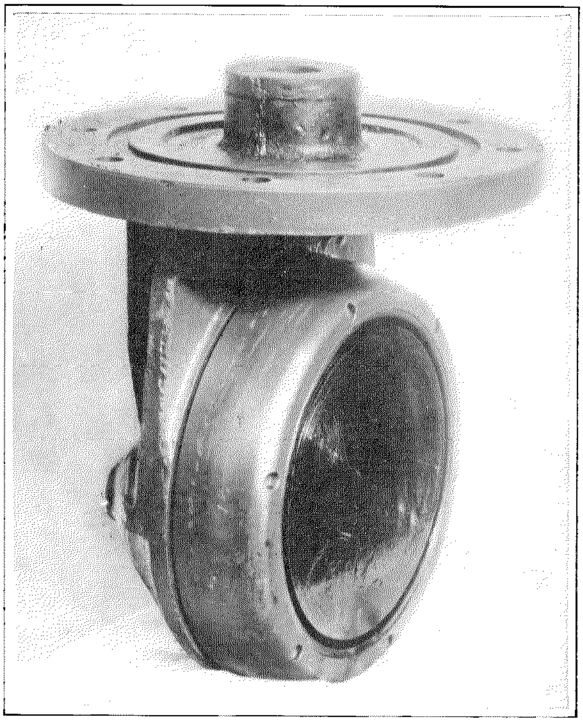
One may demonstrate by the electrometer the charge released by 0.5 gramme of quartz, and the sheet has sufficient power of resistance to support the traction of 5 kilogrammes. Thus an instrument capable of measuring quantities of electricity proportionate to the weight varying from 1 to 10,000 is available. This apparatus was shown at the Electrical Exhibition held at the Paris Observatories in 1885.

After Curie's discovery of the direct piezoelectric phenomenon, Lippmann published a theoretical work on the converse phenomenon: the geometrical deformation of the crystal when it is placed in an electrical field. Lippmann, founding his conclusions both on the principles of the conservation of energy and of electricity as well as on the properties of the direct phenomenon, was able to foresee and demonstrate in advance the special properties of the converse phenomenon.[1] He even gave the means of calculating beforehand the crystal size for a predetermined potential difference when the quantity of electricity released by a predetermined pressure is known.

The two converse phenomena are connected by the general law (enunciated by Lippmann), which is nothing but a generalization of Lenz's law. In effect, the converse phenomenon always tends to oppose the production of the earlier phenomenon.

The initial form of the apparatus foreseen by Curie for illustrating these phenomena was the following:

Several discs, cut perpendicularly to the axis, are provided with metal electrodes and superimposed by being separated by isolating blocks. The whole pile is tightly squeezed in a press, one of the discs being connected to the isolated quadrant of an electrometer and to the earth. One surface of the other disc may be placed in connection with a source of potential difference, the other surface of the same disc being connected to ground. After equilibrium has been established, the difference of potential may be applied. Because of the converse effect, the disc undergoes deformation; and, since the press holds it rigidly, it exerts supplementary pressure on the disc connected to the electrometer. This pressure is made evident by the appearance of a charge on the quadrant.


Ultra-sonic Transmitting Apparatus.

A second and more sensitive arrangement allowed Curie to make the deformation of the crystal directly evident.

Two very thin plates of quartz are cut parallel from the same block of quartz and normally to an electrical axis. Their contour has the form of an elongated rectangle. The width of the sheet is parallel to the optical axis and the length is normal both to the optical and electrical axes.

The two identical sheets are ground until they are only some hundredths of a millimeter thick. They are glued together with Canadian balm so that the electrical axes are in opposite directions in the two sheets and the external surfaces of the double sheet are silvered. If a difference of potential is established between the two silvered surfaces, one of the sheets tends to elongate itself in the direction of its length and the other to shorten itself. Since they are stuck together, the double sheet bends and the convexity is on the side of the sheet which elongates itself. The phenomenon is amplified by fixing to the free extremity a long light needle.

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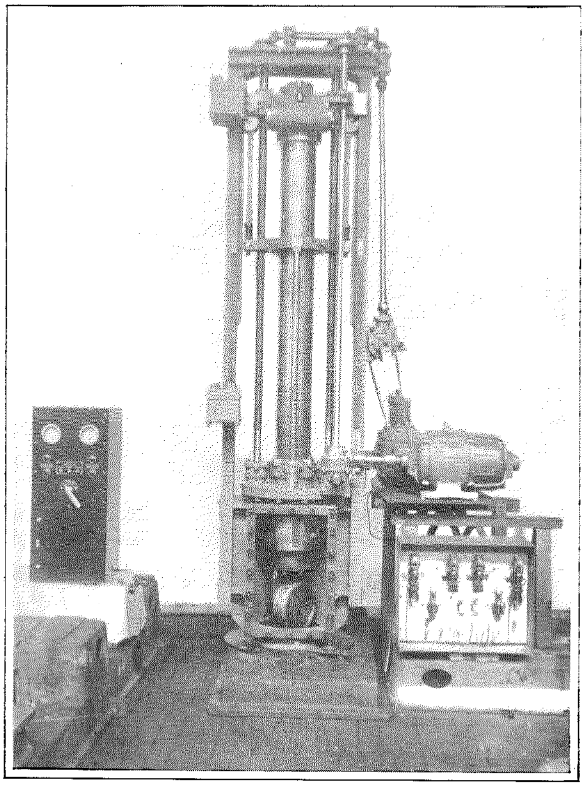
[1] "The Principle of the Conservation of Electricity," *Annals of Chemistry and Physics,* 1881, p. 145.

These very delicate sheets (1/30 millimeter for each sheet with 80 centimeters of length) have been cut by Werlein, an optician of great talent. There are thus obtained instruments which are sensitive to 5 volts and may serve up to 1,000 volts. They have permitted measurements of the piezoelectrical constant corresponding to the deformation under the influence of a field. The deformation foreseen by Lippmann's theory is an elongation in the direction of the electrical axis of the crystal, this elongation being proportional to the difference of potential:

$$dx_F = KdV.$$

The theory permits determination of the fraction dx/dV when the elastic force is constant, and it is exactly equal to the piezoelectric modulus K of Curie's formula, where,

$$dQ = KdF \text{ and } K = 6.36\ 10^{-8}.$$



Ultra-sonic Transmitter with a Device for Submerging and Electric Control of Movements.

The Work of Voigt—1890-1892

Some years later Voigt published some very important papers wherein he gave a complete theory of the piezoelectric properties of crystals. In reality, by reason of the anisotropism of the substance, the application to a crystalline sheet of a force directed other than along the optical axis, also produces piezoelectrical phenomena. One may find a relation between the electrostatic polarization of the substance and the component parts of the force which provoke this polarization.

From a purely elastic point of view, Voigt stated that the pressure components are linear functions of the differential quotients which represent the deformations. If an element of thickness dx is displaced by u, following the direction x, one can write $x_x = du/dx$. This term represents the contraction in the direction x.

In the same way: $y_y = \frac{dv}{dy}$ and $z_z = \frac{dw}{dz}$,

but the molecular displacement in the direction of the axis x changes from one point in the crystal to another in all directions. One may express the deformations of shearing by the quantities:

$$y_z = \frac{dv}{dz} + \frac{dw}{dy}, \qquad z_x = \frac{dw}{dx} + \frac{du}{dz}, \qquad x_y = \frac{du}{dy} + \frac{dv}{dx}$$

and Voigt's relation between the components: X_x, Y_y, Z_z, Y_z, Z_x, X_y, and the differential quotients are the following:

$$\begin{aligned}
-X_x &= C_{11}\, x_x + C_{12}\, y_y + C_{13}\, z_z + C_{14}\, y_z + C_{15}\, z_x + C_{16}\, x_y,\\
-Y_y &= C_{21}\, x_x + C_{22}\, y_y + C_{23}\, z_z + C_{24}\, y_z + C_{25}\, z_x + C_{26}\, x_y,\\
-Z_z &= C_{31}\, x_x + C_{32}\, y_y + C_{33}\, z_z + C_{34}\, y_z + C_{35}\, z_x + C_{36}\, x_y,\\
-Y_z &= C_{41}\, x_x + C_{42}\, y_y + C_{43}\, z_z + C_{44}\, y_z + C_{45}\, z_x + C_{46}\, x_y,\\
-Z_x &= C_{51}\, x_x + C_{52}\, y_y + C_{53}\, z_z + C_{54}\, y_z + C_{55}\, z_x + C_{56}\, x_y,\\
-X_y &= C_{61}\, x_x + C_{62}\, y_y + C_{63}\, z_z + C_{64}\, y_z + C_{65}\, z_x + C_{66}\, x_y.
\end{aligned}$$

Conversely, the components of the deformations x_x, y_y, z_z, y_z, z_x, x_y, may be expressed by the function of the components of the pressure:

$$\begin{aligned}
-x_x &= S_{11}\, X_x + S_{12}\, Y_y + S_{13}\, Z_z + S_{14}\, Y_z + S_{15}\, Z_x + S_{16}\, X_y,\\
-y_y &= S_{21}\, X_x + S_{22}\, Y_y + S_{23}\, Z_z + S_{24}\, Y_z + S_{25}\, Z_x + S_{26}\, X_y,\\
-z_z &= S_{31}\, X_x + S_{32}\, Y_y + S_{33}\, Z_z + S_{34}\, Y_z + S_{35}\, Z_x + S_{36}\, X_y,\\
-y_z &= S_{41}\, X_x + S_{42}\, Y_y + S_{43}\, Z_z + S_{44}\, Y_z + S_{45}\, Z_x + S_{46}\, X_y,\\
-z_x &= S_{51}\, X_x + S_{52}\, Y_y + S_{53}\, Z_z + S_{54}\, Y_z + S_{55}\, Z_x + S_{56}\, X_y,\\
-x_y &= S_{61}\, X_x + S_{62}\, Y_y + S_{63}\, Z_z + S_{64}\, Y_z + S_{65}\, Z_x + S_{66}\, X_y.
\end{aligned}$$

In these expressions :

$$C_{iK}=C_{Ki} \text{ and } S_{iK}=S_{Ki},$$

the relations are entirely general in any elastic substance, but the particular supplementary relations between the numerical coefficients characterise the type of symmetry in a given crystalline substance.

For quartz, choosing for optical axis the axis of Z, we have the following table for the coefficients C and S :

$$\begin{array}{cccccc} C_{11} & C_{12} & C_{13} & C_{14} & 0 & 0 \\ & C_{11} & C_{13} & -C_{14} & 0 & 0 \\ & & C_{33} & 0 & 0 & 0 \\ & & & C_{44} & 0 & 0 \\ & & & & C_{44} & C_{14} \\ & & & & & C_{66} \end{array} \qquad \begin{array}{cccccc} S_{11} & S_{12} & S_{13} & S_{14} & 0 & 0 \\ & S_{11} & S_{13} & -S_{14} & 0 & 0 \\ & & S_{33} & 0 & 0 & 0 \\ & & & S_{44} & 0 & 0 \\ & & & & S_{44} & 2S_{14} \\ & & & & & S_{66} \end{array}$$

The relations of elasticity thus simplified, there remains :

$$\begin{aligned} -X_x &= C_{11}\, x_x + C_{12}\, y_y + C_{13}\, z_z + C_{14}\, y_z \\ -Y_y &= C_{11}\, y_y + C_{13}\, z_z - C_{14}\, y_z \\ -Z_z &= C_{33}\, z_z \\ -Y_z &= C_{44}\, y_z \\ -Z_x &= C_{44}\, z_x + C_{14}\, x_y \\ -X_y &= C_{66}\, x_y \end{aligned}$$

$$\begin{aligned} -x_x &= S_{11}\, X_x + S_{12}\, Y_y + S_{13}\, Z_x + S_{14}\, Y_z \\ -y_y &= S_{11}\, Y_y + S_{13}\, Z_x - S_{14}\, Y_z \\ -z_z &= S_{33}\, Z_x \\ -y_z &= S_{44}\, Y_z \\ -z_x &= +S_{44}\, Z_x + 2S_{14}\, X_y \\ -x_y &= S_{66}\, X_y \end{aligned}$$

where

$$C_{66} = \tfrac{1}{2}\,(C_{11} - C_{12}) \text{ and } S_{66} = 2\,(S_{11} - S_{12}).$$

In addition, in a general way, we have the following relations between the coefficients C and S,

where h, i and $K = 1\text{–}2 \cdots 0$

$$\Sigma\, C_{hi}\, S_{hi} = 1 \text{ and } \Sigma\, h\, C_{hi}\, S_{hK} = 0\ i/K$$

For quartz, we have :

$C_{11} = 85.46\ 10^{10}$ Dyn cm ^{2}, $S_{11} = 12.95\ 10^{-13}$ cm ^{2}/Dyn,
$C_{33} = 105.62\ 10^{10}$ Dyn cm ^{2}, $S_{33} = 9.88\ 10^{-13}$ cm ^{2}/Dyn,
$C_{44} = 57.12\ 10^{10}$ Dyn cm ^{2}, $S_{44} = 20.05\ 10^{-13}$ cm ^{2}/Dyn,
$C_{12} = 7.25\ 10^{10}$ Dyn cm ^{2}, $S_{12} = 1.69\ 10^{-13}$ cm ^{2}/Dyn,
$C_{13} = 14.35\ 10^{10}$ Dyn cm ^{2}, $S_{13} = -1.54\ 10^{-13}$ cm ^{2}/Dyn,
$C_{14} = 16.82\ 10^{10}$ Dyn cm ^{2}, $S_{14} = 3.81\ 10^{-13}$ cm ^{2}/Dyn.

The direct piezoelectric effect represents the dependence between the deformation of the crystal and the electrical polarization of the substance :

$$\begin{aligned} P_x &= E_{11}\, x_x + E_{12}\, y_y + E_{13}\, z_z + E_{14}\, y_z + E_{15}\, z_x + E_{16}\, x_y, \\ P_y &= E_{21}\, x_x + E_{22}\, y_y + E_{33}\, z_z + E_{24}\, y_z + E_{25}\, z_x + E_{26}\, x_y, \\ P_z &= E_{31}\, x_x + E_{32}\, y_y + E_{33}\, z_z + E_{34}\, y_z + E_{35}\, z_x + E_{36}\, x_y. \end{aligned}$$

The converse piezoelectrical effect, i.e., the deformation by an external electrical field, obeys the following linear equation :

$$\begin{aligned} x_x &= d_{11}\, E_x + d_{21}\, E_y + d_{31}\, E_z, \\ y_y &= d_{12}\, E_x + d_{22}\, E_y + d_{32}\, E_z, \\ z_z &= d_{13}\, E_x + d_{23}\, E_y + d_{33}\, E_z, \\ y_z &= d_{14}\, E_x + d_{24}\, E_y + d_{34}\, E_z, \\ z_x &= d_{15}\, E_x + d_{25}\, E_y + d_{35}\, E_z, \\ x_y &= d_{16}\, E_x + d_{26}\, E_y + d_{36}\, E_z. \end{aligned}$$

For the crystalline system of quartz, the piezoelectric modulus and the constants are simplified :

$$\begin{array}{cccccc} e_{11} & -e_{11} & 0 & e_{14} & 0 & 0 \\ 0 & 0 & 0 & 0 & -e_{14} & -e_{11} \\ 0 & 0 & 0 & 0 & 0 & 0 \\ d_{11} & -d_{11} & 0 & d_{14} & 0 & 0 \\ 0 & 0 & 0 & 0 & -d_{14} & -2d_{11} \\ 0 & 0 & 0 & 0 & 0 & 0 \end{array}$$

$e_{11} = 4.77\ 10^4$ $\qquad$ $d_{11} = 6.36\ 10^{-8}$
$e_{14} = 1.23\ 10^4$ $\qquad$ $d_{14} = 1.69\ 10^{-8}$

The general simplified equations are :

$$\begin{aligned} X_x &= d_{11}\, E_x, & P_x &= e_{11}\, X_x - e_{11}\, Y_y + C_{14}\, Y_z, \\ Y_y &= d_{11}\, E_x, & P_y &= e_{14}\, Z_x - e_{11}\, X_y. \\ Y_z &= d_{14}\, E_x, \\ Z_x &= d_{14}\, E_y, \\ X_y &= -2d_{11}\, E_y, \end{aligned}$$

These equations, besides the effects shown by Curie, express the possibility of obtaining piezoelectric effects by shearing.

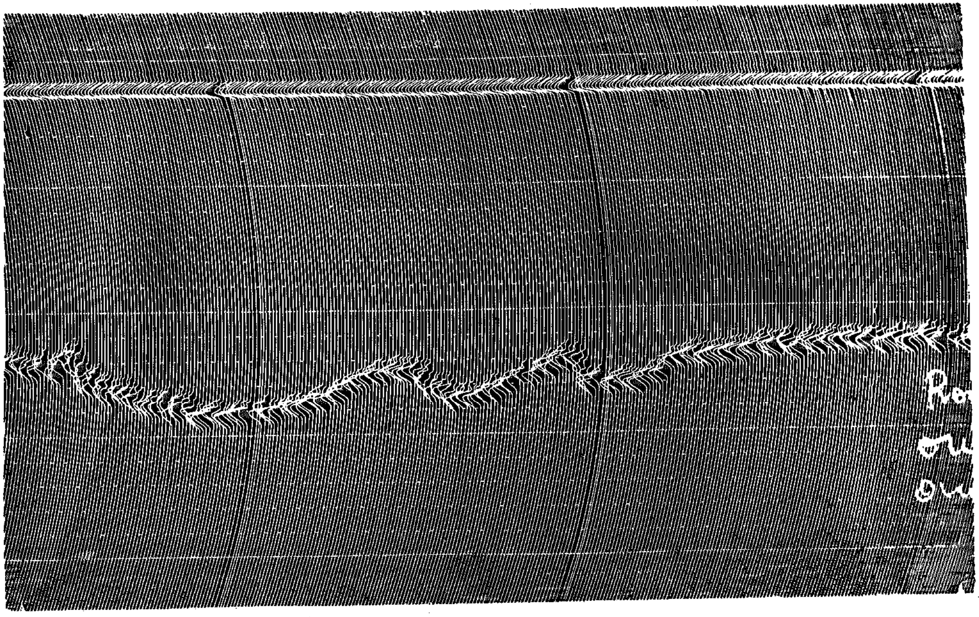
If a sheet is cut parallel to the surfaces, i.e., to the electrical axis, and if a field is applied in the direction y, there will follow a deformation of the type Z_x and another of the type X_y.

In the same way, there will here appear a polarization directed according to y, if the sheet is sheared in a perpendicular sense.

During many years, the widely known piezoelectric effects were neglected except for measuring charges.

Work of Langevin

In 1914, on the invitation of the French Ministry of Marine, work was begun which was destined to make progress in methods of defence. It was proposed to find a way which would enable a ship to detect the presence of a dangerous submerged object—a submarine or a mine. The use of echoes was suggested, the searching ship emitting a sound-wave into the water. This wave, reflected by the obstacle, would be retransmitted towards the ship which would be provided with a microphone system. The measure of the time taken by the signal to go and return would



Recording of Echo Signals on the Floor of the Sea. The Upper Recording Corresponds to the Transmission Signal, the Lower to the Floor Sounds (Echoes) Which Move as the Vessel Travels and Which Trace, Vertically to the Ship's Path, the Profile of the Sea Depths.

furnish the distance of the obstacle. If it were possible, in addition, to detect the direction, it would be possible to localize the obstacle. By reason of the great speed of sound propagation in water, however, the wavelength, which corresponds to average musical frequencies, is very great, being about 3 metres at 500 cycles, and of the same order as the dimensions of the objects to be detected. One may be sure that diffraction will play an important part and that the greatest part of the energy received by the obstacle will travel around it, only a small proportion returning to the observer.

If, on the contrary, short wavelengths are employed, the energy received by the obstacle may undergo the regular reflection and be remitted towards the observer under conditions defined by the form of the object and the laws of geometrical optics. The problem was put in a new form by Chilowsky who had observed that these interesting frequencies were commonly employed in wireless. The wavelength in water, as for instance 1.5 centimeters—very small in comparison to the dimension of a dangerous submarine obstacle—is that which corresponds to a frequency of 100,000, or 3,000 meters of electromagnetic wavelength. At the beginning of these researches, facilities for the production and reception of electrical oscillations of this frequency were already available. The problem thus resolved itself into finding a physical phenomenon which would permit the realization of the transformation of electrical energy in the form of oscillations of high frequency into elastic energy, and conversely. In the first experiments, Langevin employed electrical condensers capable of deformation for emission, and a microphone for reception. He thus obtained very remarkable results, both in communications from a distance and in the case of echoes. The apparatus, however, was fairly delicate and gave poor results. It was not until Langevin thought of utilizing the properties of quartz for the transformation of energy that the new technique achieved its definite form. Imagine a submerged sheet of quartz covered with conducting electrodes. If *U* be the potential difference and a the amplitude of deformation, we have $a = KU$, where K is the piezoelectric modulus equal to 6.5×10^{-8} when a is expressed in centimeters and U in electrostatic C.G.S. units.

Calculations show that for fairly strong emissions, immense differences of potential are necessary. It is easy to determine the amplitude of displacements transmitted to the water in order to emit a given power value in the form of a wave.

Let us fix the emitting power at 1 watt per square centimeter. A displacement of 0.4 micron is sufficient for a frequency of 40,000 cycles. By reason of the smallness of the piezoelectric modulus, this amplitude leads to a very high value of the potential difference. Nevertheless, the problem may be solved by having recourse to the same process for the reception, viz., the utilization of electrical resonance. By placing a circuit in resonance on the applied e.m.f., the potential difference is amplified to its limit and, further, it is possible to amplify the displacement by making use of elastic resonance. In effect, if we imagine a flat wave propagating itself parallel to the surfaces of the sheet, the time it takes to go and return after two reflections on the surfaces is $T = 2e/V$, where e is the thickness of the sheet and V the speed of the propagation of the elastic waves in the quartz, i.e., about 5,000 meters per second.

For 40,000 periods, it is necessary to have 6 centimeters of travel in the quartz. We thus excite a sheet of quartz 6 centimeters thick with an alternating current of 40,000 cycles per second and realize the resonance of the excitation under the vibrations of the sheet, also the amplification of these vibrations. Unfortunately, this amplification is limited by the fact that the piece of quartz is in water and cannot vibrate without damping. Calculation shows that the amplification under these conditions is only 5 ; that is to say, instead of 250,000 volts, it is possible, by making use of resonance, to employ 50,000 volts, which is still too high. This same calculation shows that when the sheet vibrates in air instead of water, the amplification is 10,000.

To illustrate the effectiveness of resonance in producing in water important transmissions of energy from an electric source of high frequency, an experiment conducted at the Laboratory in Toulon may be cited. With a power of 1 kW. in ultra-sonic waves, the quartz sheet being 1 centimeter thick, which corresponds to a frequency of 160 kilocycles, there was produced in the water a phenomenon of radiation pressure shown by a curling movement. This movement was of a peculiar nature in that if an obstacle were interposed in the water, the curl formed again on the opposite side of the sheet. Fishes placed in a basin have been killed by these ultra-sonic waves. The vibrations at the indicated frequency correspond to an intracellular pressure of five atmospheres. Even with such amplitudes, a very large surface of quartz is required to radiate great power, the crystal employed in the preceding experiment being a specimen unique in its dimensions.

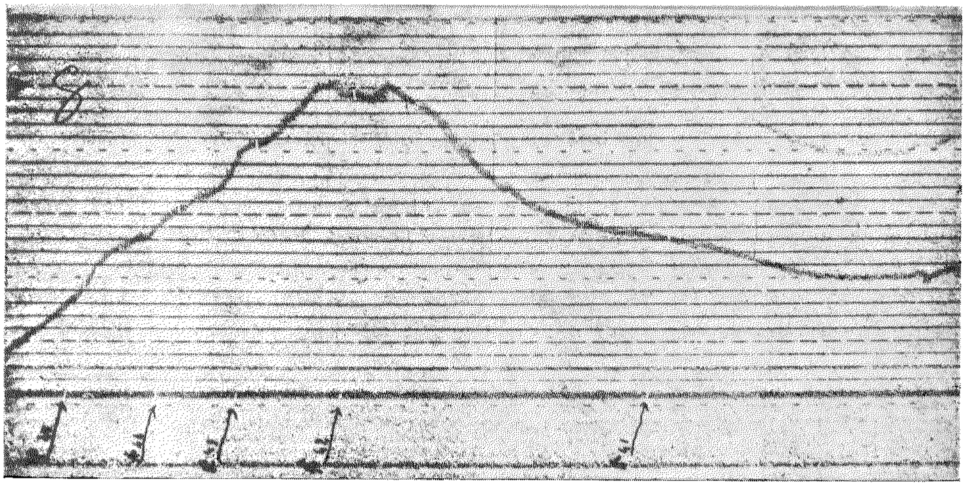
Langevin then had the idea of forming a mosaic of quartz of some millimeters in thickness into a surface of 400 square centimeters, the mosaic being glued between two steel slabs with total thickness of 6 centimeters and vibrating at 40,000 cycles per second. The substitution of steel for quartz presents the great advantage of increasing the power of amplification. When the whole is in resonance and vibrates in half waves, the quartz sheet in the center is in the region of maximum pressure, and is then subjected to stronger pressure than the neighbouring regions of the surface in contact with the water. Its efficiency is thus increased. Thanks to this arrangement, 10,000 volts are sufficient to radiate 1 watt per square centimeter instead of 50,000 volts.

The phenomena of emission and of reception are thus realized at one and the same time. The apparatus is adapted to ultra-sonic waves just as the antenna in radioelectricity is applicable to Hertzian waves. It is the submarine antenna which is both the beacon and the eye.

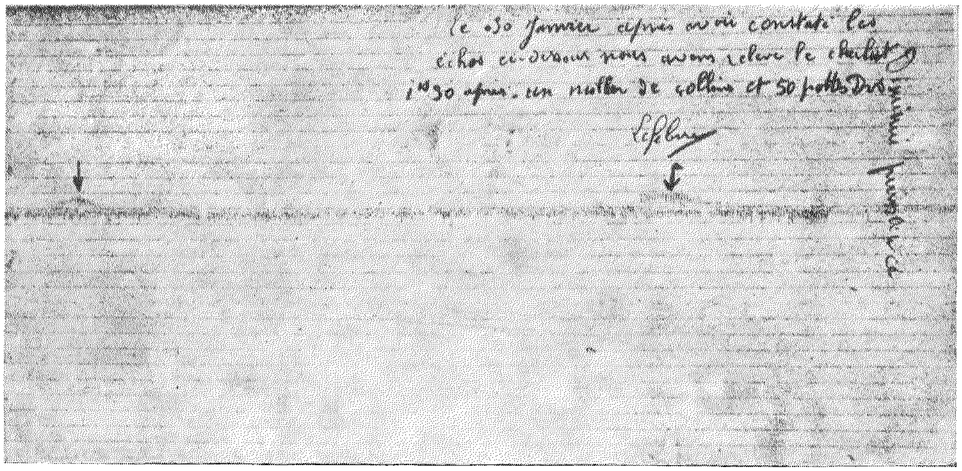
The smallness of the amplitude above calculated, which arises from the lower power of compression of water, can only be compared with the smallness of the amplitudes necessary for reception. Experiment has shown that excellent reception can be obtained when, at the frequency of 40,000, the amplitude of the ultra-sonic waves impinging on the projector is only a millionth of the amplitude of the emitted waves, i.e., an amplitude of the order of 10^{-11} centimeters. This fact is remarkable, since these amplitudes are greatly inferior to the dimensions of the molecules, which are of the order of 10^{-8} centimeters.

The ultra-sonic transmitter possesses another highly important property : the power of direction. In effect, the free surface in contact with the water functions like a flat piston in which all the points are displaced symmetrically by the alternating movement, and the vibrations in the water are transmitted in phase and in a direction perpendicular to the flat surface of the transmitter. The reflected waves are similarly in phase and an addition in amplitude occurs.

Contrariwise, in an oblique direction with an inclination of α from the perpendicular to the surface, the paths traversed on the straight line



Recording by a Chemical Photographic Process of the Ocean Contour, Indicating the Presence of a Wreck.



Duplication of the Depth Sounds (Echoes) Indicated at the Two Points Marked by Arrows and Caused by the Presence of a School of Fish. Their Presence was Checked by the Trawler Carrying the Ultra-sonic Apparatus.

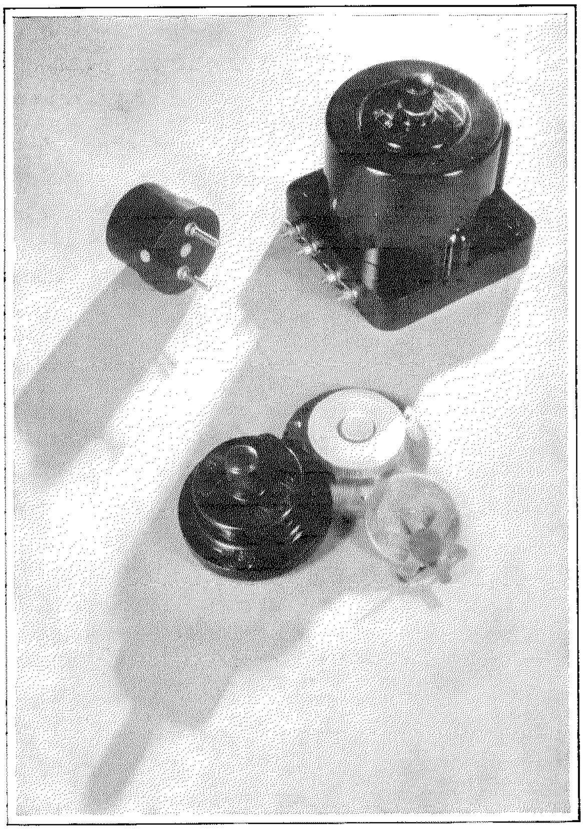
parallel to this direction are not the same. The difference between the lengths of these paths grows with the distance from the point of emission considered as the point A, and reaches the value $D \sin \alpha$. Let us suppose that $D \sin \alpha = \lambda/2$; the vibration emanating from A is opposite in phase to that of the point of origin. If the surface of emission be circular, we have a direction of minimum zero for:

$$\sin \alpha = 1.2 \frac{\lambda}{D}.$$

If $\lambda = 5$ cm. and $D = 30$ cm.,

$$\sin \alpha = 1.2 \frac{5}{30} = 0.2.$$

The emission, which is intense in the perpendicular direction, is annulled in all directions which form an angle of 10 degrees. Beyond this angle we find an amplitude noticeably diminished and there is no more concordance of phase. A little more than 90 per cent. of the energy emitted is found concentrated in a cone with an angle of 2α at the apex, and this angle becomes more acute in proportion as the wavelength diminishes.



Thermostat and Le Matériel Téléphonique Quartz Holder.

The directivity of emission is accompanied by directivity of reception. Let us suppose that a flat wave arrives parallel to the surface. It impinges at all points symmetrically with respect to the amplitude, and the resulting movement is maximum. On the contrary, if the wave arrives obliquely, it is not in phase at all points. The effect of directivity is as marked at reception as at emission.

Application of Ultra-Sonic Waves

1. APPLICATION TO SOUNDING DEPTHS AT SEA

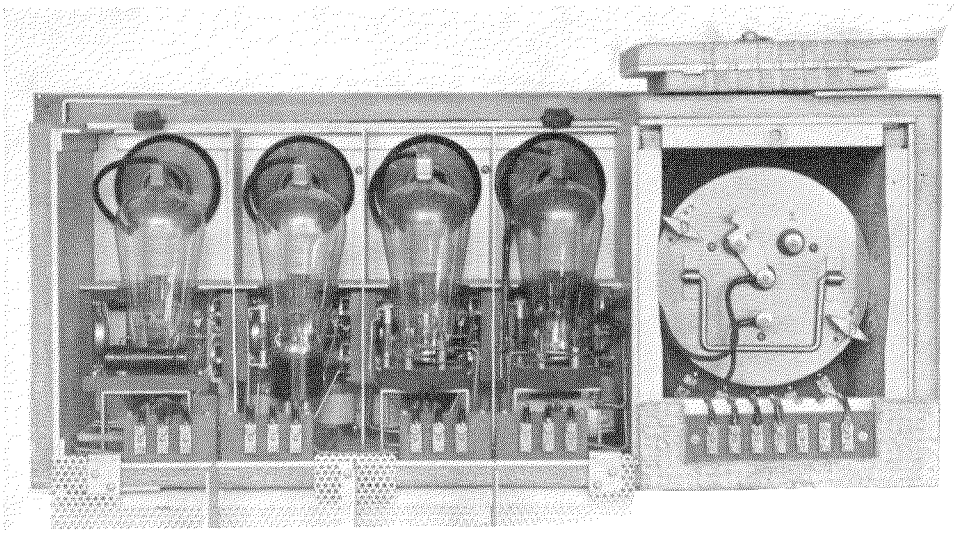
   The horizontal projector placed beneath the ship emits a ray which is reflected from the ocean bottom. A very short signal, 1/100 millisecond, is transmitted and the interval of the time between the departure and return $d = Vt/2$ is measured. The times of departure and arrival of the signal are recorded on the same strip of paper. Since the signals are regularly spaced, the profile of the bottom of the sea along the ship's course may be measured.

2. APPLICATION TO SIGNALING AND HORIZONTAL DETECTION

   A projector with a mobile vertical axis enables brief signals to be sent successively in all directions. When a submarine obstacle exists in the direction in which a ray has been emitted, an echo signal is received at the end of a period, depending on the distance of the obstacle. The position of this obstacle in relation to the ship is thus defined in polar co-ordinates. In effect, the support of the projector carries a mobile graduation.

   Such a projector has been proposed for discovering the position of icebergs, submarines, and mines.

   The entrance to the Port of Calais has been furnished with an ultra-sonic projector. The signals emitted are received on the boats coming from Dover and permit the entrance to the harbour to be found with ease, even in the case of fog. The arriving boat turns its projector in the direction of



Master Oscillator and Thermostat.

maximum intensity, thus furnishing it with the direction of the station of emission. In addition, a radio antenna transmits a signal simultaneously with the submarine signal. The entering ship possesses an antenna regulated to the same wavelength. It, therefore, registers two successive signals: the first, Hertzian; the second, ultra-sonic. The interval of time between the two permits the distance to be known. Finally, the ultra-sonic apparatus, modulated to the frequency of the voice, makes two-way submarine telephony practicable.

The Use of Quartz for Frequency Stabilization

Up to 1922, one may say that in the realm of alternating currents of high frequency, only electrical oscillations of circuits containing self-inductance and capacity were employed. In this system the energy accumulated in the condenser passes alternately from the electrostatic to the electromagnetic form, the period of the circuit, according to Kelvin, being:

$$T = 2\pi \sqrt{\frac{LC}{1 - \frac{CR^2}{4L}}}.$$

All these quantities can change with temperature; the accuracy of a good triode oscillator is not higher than one part in ten thousand.

In the ultra-sonic apparatus of Langevin, the alternating phenomenon is the successive reflections of flat waves on the surface of a steel block with a frequency defined by the thickness of the block and by the rate of propagation of elastic waves. These two physical quantities being completely constant, the time of the double journey of the wave is rigidly fixed.

This particular stability of the natural period of a vibrating bar had been observed by Langevin who had given a complete theory of the vibrations of a quartz sheet with parallel surfaces, and of a quartz sheet glued between two steel slabs.[2] The paper on this subject was submitted at the Washington Congress of June, 1917. In 1922,[3] Cady published a simple theory, permitting consideration of the crystal in the neighbourhood of a resonance as an oscillating circuit of which the constants $L\ C\ R$ may be calculated by functions of the physical constants of quartz and its dimensions.

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[2] Sound Transmitter for Underwater Signaling, British Patent 145691, 1921.

[3] "Theory of Longitudinal Vibrations of Viscous Rods," *Physical Review*, 1922, p. 191.

One may thus, in a manner familiar to electrotechnicians, take account of the interaction between a source of alternating current and a sheet of quartz. Cady and Pierce subsequently published papers wherein they indicated the simple means by which the oscillations of the crystal may be maintained by association with a triode.

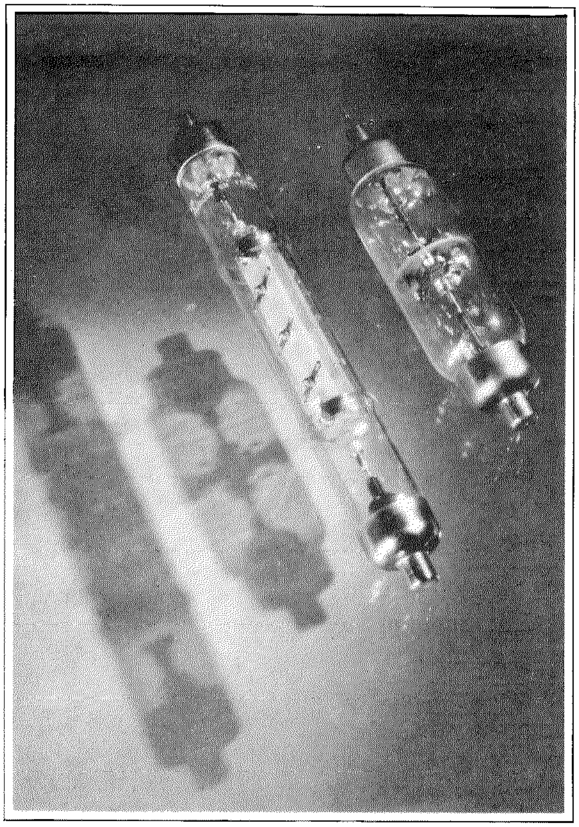
Cady, in his first publication, showed the absorption of energy in a very narrow frequency band, thus opening the path for future study on crystal filters.

In January, 1920, when filing his first patent application (now United States Patent 1,450,246), Cady was working with crystal plates provided with the usual tin foil coatings. In neither this patent nor patent 1,472,583 (filed May, 1921) did he consider the influence of an air gap between the plate and either of its electrodes.

Dye demonstrated the influence of the air-gap contained between an oscillating quartz and its electrodes. He was able to put in evidence the existence of stationary waves in the air. Thanks to its extraordinarily weak decrement, the quartz sheet, whose oscillations are easily maintained by a triode, preserves a frequency which varies only very slightly with changes in the holding condition. As soon as this important fact was realized, the use of crystals was proposed for defining exactly the frequency of master oscillators of commercial transmitters.

It may be said that, at the present moment, radio emission is merely the translation amplified in electrical form of the mechanical movement of a thin piezoelectric sheet which is both fragile and precious, which is breakable by a force of a few grammes, and which, nevertheless, controls, in the case of certain emissions, a power of several hundred kilowatts.

Every electrical oscillator functioning periodically may be compared to a clock. The transmitters of 20 years ago with arcs, sparks or triodes, in relation to the modern crystal transmitters, had the irregularity of the clepsydrae or hour-glasses compared to the perfect working of an astronomical clock.



A Vacuum-Mounted Crystal Oscillating on Partial 3 for the Crystal-Controlled Clock of the Laboratoire National de Radioélectricité (Le Matériel Téléphonique Product).

This wonderful frequency stability has permitted the simultaneous operation of a very large number of radio transmitters. Each transmitter emits a frequency-spectrum, restricted to a narrow, strictly limited band, with a rigidly constant carrier frequency. All the emissions of one country constitute a complete spectrum whose individual narrow bands are separated from the neighbouring bands as sharply as possible. Without stability, all these frequency bands would be changing continuously, and interference and superposition would render the stations unintelligible. Thanks to crystal control, the graphs published monthly by the International Office of Control at Brussels register variations of frequency which are very small for the majority of stations, and, for certain ones, do not exceed a few cycles. It has thus been possible to multiply the number of stations of emission without confusion ; also, to transmit simultaneously from several distinct stations with the same modulation and wavelength, but with different master oscillators.

This triumph of skill has been made possible by the use of master oscillators especially adapted to very high precision, the maximum variation during an interval of 6 hours being of the order of one part in ten millions. It may be noted that this precision is of the same order as that of an astronomical clock.

Frequency-Measurement Apparatus

All frequency measurement is merely a measure of time. To measure high frequencies is, indeed, to measure very short intervals of time. The unit of time, common to all, or almost all the systems of measurement, is the second, the 1/86,400 part of the average solar day. The second is in reality only an auxiliary unit. The solar year alone can be defined by astronomical measurements, which enable our unit of time to be linked to the course of the stars. It is the solar year which is the true physical unit of time. The solar year lasts about 31,000,000 seconds.

Let us suppose that we wish to measure, approximately within the precision of one part in a million, the period of an electrical oscillator, the frequency of which is 5,000 kilocycles. This means that we must measure the time interval of 2×10^{-7} seconds to the nearest fraction of 10^{-6}. In other words, we must be able to determine a time interval of 2×10^{-13} seconds by disposing of a physical unit of the value of 31,000,000 seconds. The unit here is 1.5×10^{20} times greater than the quantity to be measured.

In the domain of measurements of length, the problem would be to determine a length of one millimeter by employing a ruler of which the length was 1.5×10^{20} millimeters. For the light to traverse this ruler, a period of 5×10^{8} seconds, i.e., about 16 solar years, would be necessary.

Most fortunately, in the case of measurements of time, we benefit from a rigid physical phenomenon. It is the isochronism of the oscillations of the pendulum affording a means for adding an immense but well determined number of brief, similar time intervals and comparing this sum with the standard of time. The astronomical clock is in reality only a meter which enables us to know how many oscillations are made in a year by means of a pendulum which is, as far as possible, independent of external circumstances in its movement. By admitting the necessary postulate of the isochronism of oscillations, our unit of time becomes that period of the pendulum which is 1/31,000,000 of the solar year. This unit is, of course, convenient for measuring purposes.

To continue the preceding example, when it is necessary to demonstrate a variation of one part in 10 millions in the frequency of an oscillator of 5,000,000 cycles per second, it still remains for us to determine a very small time interval with a unit which is 5×10^{12} times greater.

In the domain of measurements of length, the problem would be comparable to that of the measurement of one millimeter with a ruler of 5×10^{12} mm., i.e., 16 light seconds or about nine times the distance from the earth to the moon.

To resolve this problem we here admit once more the postulate of the isochronism of the oscillations of quartz, and we set up a quartz clock which resembles in many ways an astronomical clock or, more precisely, a chronometer. Here the fundamental period will be that of the crystal, and is solely defined by the elastic properties of the crystal and its linear dimensions, similar to that of the balance-wheel of a chronometer.

To complete the clock, we require a meter comprising an electrical demodulator system. If the period of the crystal be 1/100,000 part of a second, it is arranged so that the quartz at the end of each group of ten periods sets up a secondary electrical phenomenon (charging a neon lamp, for instance); then this first neon lamp will act on a second after ten of its own charges, and so on, and we end by disposing of a periodical current which presents 100 maxima per second.

With this current a synchronous motor would be turned, and henceforth the demultiplication will take place by mechanical processes, as in ordinary clocks. It only remains to compare the working of the quartz clock with the working of an astronomical clock. A quartz clock in reality furnishes us with an auxiliary unit of time shorter than the astronomical clock, i.e., 1/100,000 second.

This time or unit is on the scale of the periods of the oscillations to be measured. The postulate, on which the accuracy of the measurements is based, is the isochronism of the quartz oscillations. The probabilities are that this isochronism is much more rigid than that of the oscillations of the pendulum of the astronomical clock.

The period of the astronomical pendulum may be influenced by many secondary phenomena, i.e., variations of atmospheric pressure, of temperature and, especially, of variations in the intensity of the field of gravity. Thus we may hope that, thanks to the use of quartz clocks, it will be possible to demonstrate more clearly certain anomalies of the earth's movement.

Temperature Coefficients

The period of a crystal is, nevertheless, dependent on a certain number of external physical agents, among which temperature plays a preponderant part. To avoid the inconvenience due to this phenomenon, thermostatic ovens have been constructed with a temperature as constant as possible and, in certain cases, it has been possible to obtain a temperature stability of the order of 1/100 of a degree. Recently, Lack and Marrisson have proposed the coupling of crystals so as to take advantage of different modes of vibration, propagating in different directions and having temperature coefficients of opposite signs. Thanks to this coupling, for a given quartz specially cut, there exist fairly extensive regions in which frequency is independent of temperature. By a suitable choice of the ratios of different dimensions, very small temperature coefficients are obtainable.

The accompanying illustration shows a quartz constructed at the L.M.T. Laboratories, Paris, for the National Laboratory of Radioelectricity. This quartz is an elongated bar, Curie-ground. Its length is parallel to the optical axis and its thickness to the electrical axis. It vibrates on the third partial by means of three pairs of electrodes cross-connected. Wires, knotted along the nodal lines, suspend the bar in a moulded quartz frame in the evacuated center of a sealed bulb. The bulb is placed in a thermostatic oven. Electrical mounting, connected with the crystals, permits one to obtain simultaneously 50,000 oscillations of different frequencies, all known with the same accuracy as the fundamental quartz frequency. By means of recording systems, it is possible to obtain a permanent comparison between this quartz clock in the National Laboratory and all the clocks of mean time in the Paris Laboratory, each clock being compared during 5-minute periods by rotations of about a half hour. This crystal has oscillated continually for several years.

The subsequent studies of Marrisson, Straubel, Koga, and Bechmann (thanks to the advanced study of the elastic properties of quartz in the light of Voigt's equations) led to the discovery of angles for cutting the crystalline sheets in which the temperature coefficient of the rate of wave propagation parallel to the external faces of the specimen under consideration, is very small and may become nonexistent. Further, angles of cutting may be found in which the deformation in the direction of the propagation is not accompanied by deformation in the perpendicular direction. In this case, the principal movement of the sheet is isolated and is no longer coupled to a secondary movement whose period and temperature coefficient fall between the period and the coefficient of the whole.

As a consequence of these studies, we now know how to grind crystalline sheets whose period is practically independent of temperature and which may be employed without thermostatic ovens.

Different Applications of Piezoelectricity

MEASUREMENT OF PRESSURE

In the measurement of pressure with the aid of crystals, no use is made of the phenomenon of elastic resonance at high frequency.

By means of an electrometer tube, followed by an amplifier and an oscillograph, the succession in the time of electrical polarizations produced in the crystal by external pressure is registered. Apparatus of this type makes possible the study of widely differing phenomena. The order of magnitude of the forces which may thus be measured and registered varies between 1 gramme and 30 tons.

Applications of these manometers have been made by André Langevin in the study of hydrodynamical and physiological mechanical phenomena. With these manometers he has been able to obtain accurate records of discontinuous phenomena which are produced in water pipes.

The records show the exact physical nature of the phenomena, indicate the theory of the formation of discontinuities, and help to explain the laws of the united motion of the liquid column which fills the pipe and which is provoked by these discontinuities of pressure.

A manometer of a similar type makes possible the study of the very slight pressure on the veins and arteries which the circulation of the blood produces in the human organism.

A variant of this apparatus permits the recording of the strain produced by railway carriages on the rails. The same method is applied to the study of the vibration of bridges and other metallic structures.

Finally, by means of these manometers, it has been possible to measure the explosive pressure in the cylinders of combustion motors and in guns.

Electric Filter Crystals

If the use of quartz in radio transmitters, by assuring the stability of the carrier wave of each station, permits the frequencies of different stations in the same country to be placed more closely together, it is at the same time necessary to make the receivers very selective.

The ideal selectivity characteristic of a receiver should allow the free transmission of all frequencies, without amplitude distortion, within the selected band and completely suppress all other frequencies falling outside the desired range. For the most efficient use of the frequency spectrum, the abrupt frequency discrimination between the passed frequency range and the attenuated frequency range must be realized in the narrowest possible frequency space.

Even the employment of the most improved types of coils and condensers in the construction of such sharp cut-off selecting circuits leaves much to be desired. W. P. Mason has shown that it is possible to quite closely approach the ideal by the use of crystal elements in resonant type, selecting networks that have small percentage band widths and which attenuate in small percentage separation ranges.

Here also success is due to the extremely low damping rate of the mechanical oscillations of the solid. The piezoelectric properties of quartz make it possible for damper circuits to benefit in certain domains of frequency from the properties of mechanical resonators with which they are coupled.

Application to Acoustics

Quartz, little capable of deformation but very sensitive to pressure, is specially well adapted to the reception of sound waves transmitted by water. It is thus that piezoelectric microphones have been constructed to listen to underwater sounds (noises of ships, propellors, and submerged submarines).

For uses of this kind,when very slight damping of the elastic solid is not necessary, and the piezoelectrical effect needs only to be a qualitative translation of external pressure, it is possible to replace the fairly weighty quartz by Rochelle salt, double tartrate of sodium, and potassium, which is more economical and, besides, more sensitive, since its piezoelectric modulus is greater.

Minute fragments of Rochelle salt, properly cut, constitute very good, light pick-ups for gramophone records.

Finally, the converse piezoelectrical effect enables the construction of telephones with a membrane worked by a piezoelectric motor and of loudspeakers better fitted than the electromagnetic loudspeakers to the reproduction of very high frequencies ("Tweeters").

In these last applications we see that in high frequency and other applications piezoelectric phenomena tend to be substituted for the ferromagnetic property as an intermediary between the two forms of energy—the electrical and the mechanical.

Conclusion

Too much emphasis cannot be placed on the extreme importance of the discovery of the piezoelectric properties of quartz from the viewpoint of electrical high frequency technique. As in the case of ferromagnetism, known of old, this discovery yielded additional facilities for the conversion of mechanical to electrical energy, and vice versa.

In iron and steel, magnetic polarization may be localized either permanently, as in the case of magnets, or intermittently, as in the case of soft iron. To obtain good results in the transformation of energy, the displacement between the magnetic and the electrical conductive systems must be relatively slow. In the case of ferromagnetism, the elasticity of matter is not relevant, and the frequencies involved are relatively low and the energy great. In a crystal, however, the average dielectric polarization is always zero, and molecular displacement is imposed on the mass by an external force which disturbs equilibrium and gives rise to dielectric polarization, which is a direct consequence of the force and which vanishes simultaneously with that force.

In reality, a molecular electromagnetic phenomenon analogous to piezoelectricity exists in iron, i.e., the magnetostriction or molecular deformation of iron when magnetized under the influence of an external magnetic field. When desiring to apply this property to high frequency phenomena, one perceives that the loss through Foucault currents or through magnetic hysteresis is considerable and that the resulting exchange of energy is small. Quartz, on the contrary, is well adapted to high frequency work. Its losses due to dielectric hysteresis are negligible, its electric conductivity is strictly zero, and its internal molecular friction is very slight. Actually, the damping of crystalline resonators is due for the most part to the friction of the quartz against its supports.

If this friction be diminished by suspending the specimen from its nodal points and if the air-damping be suppressed by placing an oscillator in a vacuum, decrements lower than 10^{-6} are obtained. This means that in a sheet of say, 5 centimeters length, a flat isolated wave, propagating itself parallel to the faces, traverses 100 kilometers by undergoing two million successive reflections before its amplitude is diminished in the ratio of ε to 1.

Quartz, more useful than the diamond, which for man has always been a symbol of perfection in matter, is one of the most valuable substances with which nature has endowed us. Purely scientific and disinterested research was at first necessary for the discovery of its piezoelectric properties. Born of the pure genius of Curie, this new knowledge was soon revealed to be rich in unsuspected uses.

Budapest Automatic Telephone Network Reaches Stage of Six-Digit Dialling

By DEZSÖ VÉGHELY,

Chief Technical Director of the Royal Hungarian Postal Administration

A NOTEWORTHY event took place on June 27th, 1936, when the six-digit dialling system was introduced in the Budapest automatic telephone network. The transition from five- to six-digit dialling was an important stepping stone towards an unprecedentedly rapid development of telephony in Budapest, and prompts a review of the stages passed in the growth of the Budapest telephone system from the cut-over of the first automatic telephone exchange at that date.

The first section of the Budapest automatic telephone system was cut over on April 28th, 1928. When automatic service was introduced, the former manual network had, of course, to be decentralised. The traffic that previously was handled with three manual exchanges was in course of the process of automatization distributed over seven automatic exchanges. The advantages of automatic service soon became an incentive to large portions of the public, which had kept away from the telephone, to join the fold of telephone subscribers. Soon after the cut-over of the first exchange a rapid increase occurred in the number of subscribers, principally during the years 1928 to 1930, when the glamour of the novelty still continued to attract. The rapid increase is clearly indicated by the steep, ascending curve of Fig. 1. Moreover, it was due mainly to the automatic service that, in the years 1931 and 1932 when business dropped to an alarming level, few subscriptions only were lost. In 1933, the situation again changed for the better.

This change in the trend of development in effect was an admonition to the Post Office that, sooner or later, transition from five- to six-digit dialling might become necessary. The idea of introducing six-digit dialling was suggested also by the circumstance that there was no proportion in the growth of the number of subscribers in the sections allotted to each automatic exchange. While certain parts of the city developed rapidly, there was a standstill or even a retrograde tendency in others. Thus the mountainous region on the right bank of the Danube, called Buda, grew faster than other regions of Budapest. The number of telephone subscribers in that region increased from 3,000 in 1928 to 15,000 in 1933, a development unforeseen when the automatic network was planned. Consequently, certain number groups of the exchanges in this region soon became saturated.

Another reminder that five-digit dialling would not suffice any longer was the rapid growth of party-line subscribers. Party-lines soon became very popular with the Budapest public, primarily on account of the individual calling numbers and message registers at the exchange, and the secrecy of service, the outstanding features of the Budapest party-line system. As a result, party-lines have increased much to the disadvantage of main station lines.

Owing to the adoption of the individual calling number feature, a two-party party-line reduced the capacity of the exchange by an amount corresponding to two normal subscribers' stations. On the other hand, from the point of view of traffic, a party-line subscriber does not represent the traffic value computed for a single line at the time when the exchanges were planned. As a matter of fact, the traffic ratio of a party-line subscriber is about one half of that of a normal line. Consequently, it was at first considered that a party-line should take a single location only on the final and the first line finder arcs instead of the two as at present. In this case, party-line subscribers might be connected to vacant locations of the present exchange equipments at a comparatively low cost. This object, however, may be best obtained by the adoption of the six-digit dialling system. According to the 200-unit final switch system of the original 7-A Rotary System, the final capacity of the Budapest area is 200 × 10 × 10 × 10 = 200,000 when the 1st, 2nd, 3rd and final selecting stages are fully exploited. This means that, by adopting the six-digit dialling system, only the numbers ranging from 100,000 to 299,999 may be used instead of a full million, which six-digit dialling would at first glance suggest. Consequently, 3 and 4 as first digits may be used for indicating the second party to a two-party party-line. As shown in Table I, the first group selector is selected by digits 1 and 2. Accordingly, digits 152819 and 352819 may be paired in a way such that the register transforms both numbers to the same effect, with respect to the first group selector, by simultaneously marking by means of relays whether the first digit was a 1 or a 3. At final selection, when a 3 has been dialled, the trip spindle makes a complete additional turn, whereby a relay is energised in the final selector circuit and legs "a"—"b" are reversed, ringing thus taking place over leg "a" instead of leg "b." This is the well-known method of ringing the second station of a two-party party-line system. Further, the same point of the arc of the final selector corresponds to both stations marked by two numbers differing only in the first digit.

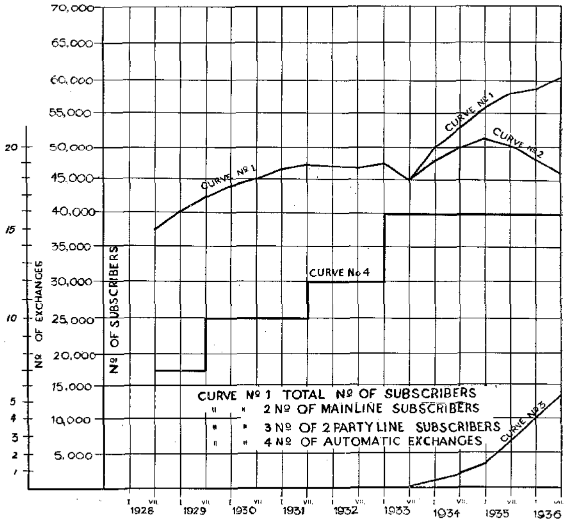


Fig. 1—*Increase in Subscribers.*

Similarly, numbers of the 200,000 field may be paired with numbers of the 400,000 field. Thus the numbers of the 300,000 and 400,000 fields are reserved exclusively for the second stations of two-party party-lines, and separate final and group selectors may be dispensed with. As the 300,000 and 400,000 fields are reserved for the second stations of two-party party-lines, it follows that these fields will be exploited only to the extent required for party-line purposes. Accordingly, an adequate number of final and selector circuit groups will require modification for the purpose of partial exploitation of the 300,000 and 400,000 fields.

The digits dialled by a calling subscriber are registered by the registers of the automatic exchange in order that they may control the selectors in due course. Therefore, to carry through the change from the five- to the six-digit dialling system, the register circuits had to be modified first. Of the sixteen exchanges of the Budapest automatic telephone area, only eight are provided with registers; the other eight, being satellites, use the registers of their respective main exchanges. There are altogether 1,442 register circuits in the eight main exchanges. The cut-over had to take place simultaneously at all exchanges, and, as a matter of course, at a time of minimum traffic. The time selected was midnight, June 27, 1936, a Saturday, followed by Sunday, the 28th, and Monday, the 29th, a holiday. This choice was made in order that the modification of all registers might be completed in due course for handling increased traffic requirements on the following working-day, June 30th. Preparatory work had started several months previously.

TABLE I

Selection	Digits	
	At 5 digit selection	At 6 digit selection
1st Gr. Select.	First	First and Second
2nd ,, ,,	Second	Third
3rd ,, ,,	Third	Fourth
Final	Fourth and Fifth	Fifth and Sixth

The following is a brief sketch of the programme as laid down at the beginning of the work. Two stages may be distinguished in the complete process:

(*a*) The preparatory stage, comprising the insertion of four new relays in each register circuit, the change-over of two relays (change of contact) and the connection of additional wires of the registers;

(*b*) The cut-over stage involving the cutting of 30,000 wires on the terminal strips and the connecting of 62,000 wires in the total network.

While this work was in progress, the circuits were placed out of service by means of the busy jacks.

Since the performance of the operations necessitated by (*b*) for each register circuit consumed the comparatively long period of about an hour, a few of the 1,442 registers were modified before the actual cut-over had taken place. For such registers the cut-over proper consisted merely in extracting the plug from the busy jack.

Inasmuch as the time available for the cut-over of the still unmodified registers was short, the terminal strip wires and the terminals ready for cut-over of this portion of the registers were connected to auxiliary jacks. The latter were used for the change-over to six-digit dialling, which took a very short time only and which was made by extracting and/or inserting a short circuiting brass plug. This secondary preparation was preceded by a long installation period. This installation work, however, was necessary in order to have available an adequate number of registers at the time of actual cut-over. All such temporary apparatus installed for the occasion was gradually dismounted and the final modification of the registers completed. The rest of the register circuits, forming a third and additional group, were at the time of cut-over placed out of service by inserting plugs into the busy jacks, the plugs remaining there until the operations of stage (*b*) were fully carried through.

Handling of the cross connecting arrangements was adequately provided for by:

1. A staff of trained help,
2. Formers used as auxiliary tools,
3. Systematic routine tests,
4. Constant supervision of the work by a staff of engineers.

Preparatory arrangements made it possible that, from the first day of normal traffic, all register circuits were serviceable and capable of handling a traffic larger even than the normal. The great increase of traffic on the first days of the new system was mainly due to the momentary forgetfulness of subscribers, who instinctively dialled five digits instead of six. Calls of such subscribers were attended to partly by plugging them into the line jack of the registers and partly by routing them to a special board by means of the so-called wrong number feature. During the first few days of the new system there was a daily average of twenty to twenty-five thousand wrong number calls.

The Cunard White Star R.M.S. "Queen Mary" Radio Installation

By Commander F. G. LORING, O.B.E., M.I.E.E.,
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W. H. McALLISTER

EDITOR'S NOTE: *The following has been extracted from a Paper, "A Survey of Marine Radio Progress, with Special Reference to R.M.S. 'Queen Mary,'" presented on 3rd March, 1937, before The Institution of Electrical Engineers, London. It forms a technical supplement to the general description of "The Radio Installation on the Cunard White Star, R.M.S. 'Queen Mary,'" published in "Electrical Communication" of July, 1936. In extracting from the original I.E.E. Paper, the sequence of subjects and the reference numbers of the illustrations have been changed to conform with the more restricted scope of the present article as compared with the I.E.E. Paper.*

The radio equipment of the "Queen Mary" was almost entirely manufactured by companies in the International System, and was supplied and installed and is operated by the International Marine Radio Company, Limited, under contractual agreement with the Cunard White Star Limited.

Principal Requirements

THE two primary considerations in deciding on the equipment to be fitted in a large passenger vessel are, firstly, navigation and safety of the ship, and secondly, the public radio-telegraph and -telephone service. While the first is still the most important function of the radio station on board, it presents no real problem and can be amply catered for by quite orthodox and standardized arrangements.

The second consideration, that of the public radio service, becomes of greater importance as the size of the ship and the passenger accommodation increases, and, in the largest transatlantic vessels, is the real deciding factor as to the equipment which is to be supplied to the ship. The volume of radio traffic handled is considerable, and it is of great importance that it be cleared with the minimum of delay.

For the R.M.S. *Queen Mary* it was calculated that four transmitting channels and four receiving channels would be required—two on the short waveband for simultaneous eastbound and westbound communication, one on the medium waveband and one on the long waveband. Automatic transmission and reception at moderately high speeds on at least two or three channels was also considered necessary.

The above remarks apply primarily to telegraph traffic. In order to provide for the radiotelephone service the conclusion was reached that simultaneous communication with both London and New York would certainly be required at times and that the most efficient and economical arrangement would be to incorporate radiotelephony in both short-wave transmitters rather than to install separate equipment.

Having determined the number of operating channels required, the next question to be settled was how to obtain them. The chief problem was the provision of multiplex working, which, in the confined space of a ship, presented no little difficulty. Not only was operation on four different wavebands required without mutual interference, but duplex working in each of these wavebands was also aimed at, up to the limits of practical working range of the transmitters.

Based upon previous experience it was clear that the primary requirements for efficient multiplexing were, firstly, separation of the transmitters and receivers with their associated aerials by as large a distance as possible; secondly, the provision of receivers having considerable selectivity and ability to withstand high voltages picked up by their aerials from the local transmitters; thirdly, the provision of transmitters as free as possible from harmonic radiation. A number of other relatively minor difficulties, such as interference between adjacent operating positions due to key-clicks, and receiver inter-action, “stay noises,” etc., also had to be overcome.

Some separation of the transmitters and receivers was not a difficult matter to achieve in so large a ship, and suitable sites for the transmitting and receiving stations 400 feet apart were obtained.

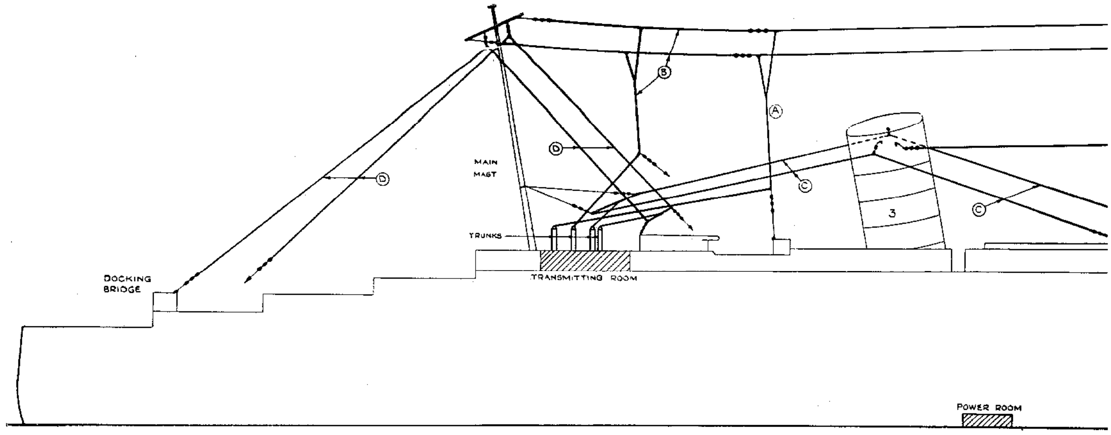


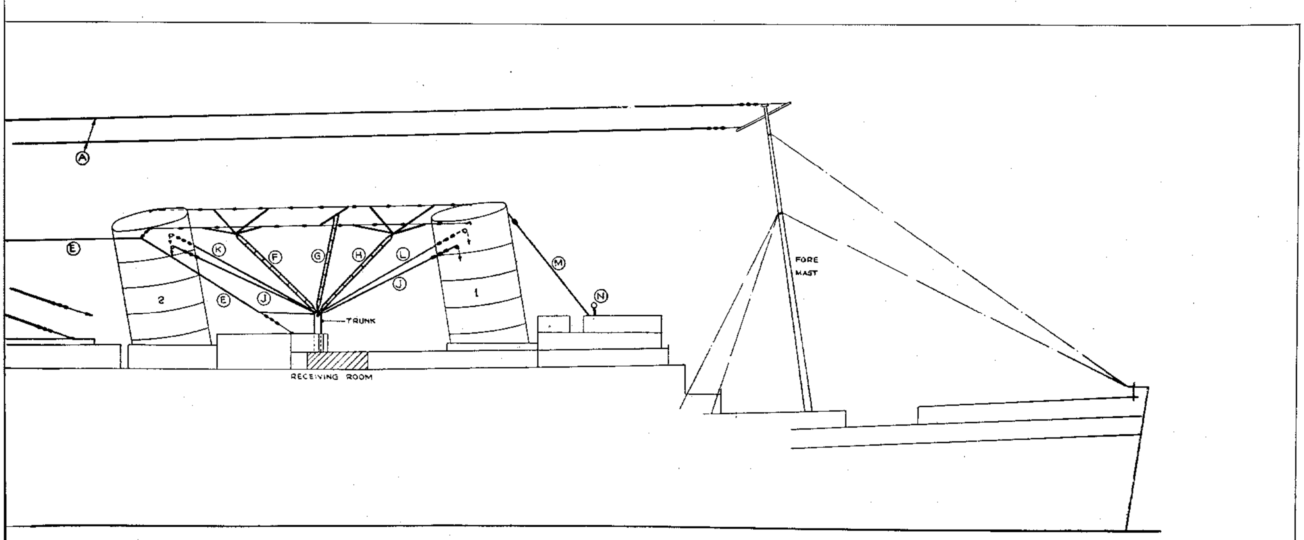
Fig. 1—*Outline of R.M.S. “Queen M*

(A) Long-wave Transmitting Aerial.
(B) Medium-wave Transmitting Aerial.
(C) Short-wave Transmitting Aerial (No. 1).
(D) Short-wave Transmitting Aerial (No. 2).
(E) Emergency and Long-wave Receiving Aerial.
(F) 13-Mc Double Doublet.
(G) 17-Mc Doublet.

One of the most important features in the rapid handling of traffic is the ability to change wavelength quickly. This especially applies to the short wavebands when combined telegraph/telephone equipments are used, since special wavelengths are allocated to each of these services, and in order not to delay either service it is necessary to be able to change from the one to the other very quickly. Consequently it was decided to provide complete remote control not only for keying and power but also for rapid selection of any one of a number of pre-selected wavelengths.

The power and frequency ranges of the transmitters remained to be decided. For the medium and long wavebands the factor limiting good communication is as a rule the signal/noise ratio. Since these frequency bands are part of the main communications of the ship, and have to carry the whole of the telegraph load at times when the short-wave channels are both occupied for telephony, or when short-wave communication is poor, it was considered necessary to provide the highest power practicable. A power of 3 kW in the aerial circuit was finally decided upon, the limiting factors being space available for installation and the maximum voltage permissible on the aerials. The transmitting aerial constants were of considerable importance in this connection, since any brush discharge would give rise to damped waves which would shock-excite the receiving aerials and prohibit multiplexing.

For short-wave communication, conditions are somewhat different. While the limiting factor, especially for telephony, is again the signal/noise ratio, experience has shown that the borderline cases are not the general rule; that is to say, for any particular frequency, conditions are generally either good or bad with the average powers in use. When conditions become bad it is better to change frequency rather than to increase power. Experience gained in the *Aquitania* and *Berengaria* showed that, with the aerial powers in use in those ships, well over 90 per cent. of radiophone calls could be satisfactorily completed. Increasing the power by 10 times, giving an increase in signal/noise ratio of some 10 db, would have added about another 5 per cent. to the total—a desirable feature, but scarcely worth the corresponding disadvantages of extra space and power supply required, greater difficulty of control, higher "stay noises," and higher initial and maintenance costs. On the other hand, it was estimated that by providing suitable directional aerials an effective increase in signal/noise ratio of between 5 and 10 db could be anticipated, equivalent to an increase in power of some 3 to 10 times. This was confirmed by preliminary experiments carried out in the *Berengaria*, when even greater increases in signal/noise ratio were reported. It was consequently decided to use an aerial power of approximately 400 watts, and to concentrate on providing the most efficient aerial system possible.



Showing Position of Radio Plant and Aerials.

(H) 8-Mc Double Doublet.
(J) 4-Mc Dipole.
(K) Medium-wave Receiving Aerial.
(L) Broadcast Receiving Aerial.
(M) Direction Finder Sense Aerial.
(N) Direction Finder.

A similar argument holds good for the receiving aerials, and experiments were carried out with different types of these in order to obtain the maximum signal/noise ratio. In this case, besides providing as much directivity as possible, interference from ship's machinery had to be avoided by suitably arranging the planes of the aerials, providing shielded feeders, etc.

LOCATION OF EQUIPMENT

The communication equipment of the *Queen Mary* is housed in three separate places on the ship, viz:

(*a*) The power room, situated near the engine room of the ship, containing the two 45-kVA motor-alternators for supplying all power to the transmitting and operating rooms.

(*b*) The transmitting room on the sun deck, containing the four main transmitters and the power control and distribution board.

(*c*) The operating room, also on the sun deck, about 400 feet away from the transmitting room, containing all receivers, telephone terminal equipments, remote-control apparatus, transmitting keys, high-speed transmitting and receiving apparatus, and a complete emergency station.

Fig. 1 shows an outline of the ship, giving the respective positions of these rooms and of the aerial system.

TRANSMITTING ROOM

This is situated at the after end of the sun

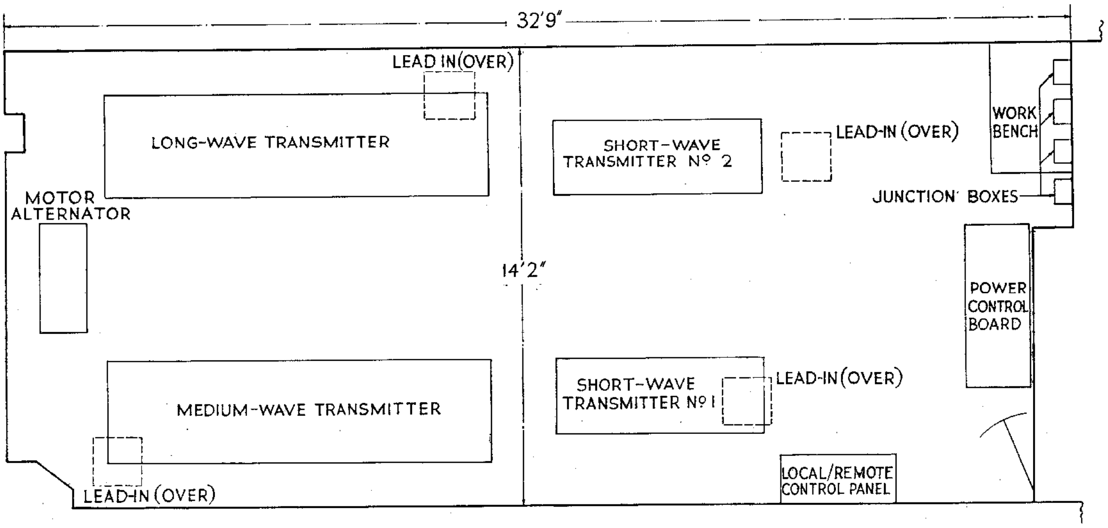


Fig. 2—Transmitting Room of R.M.S. "Queen Mary."

deck, just forward of the mainmast, and measures some 30 ft. by 14 ft. by 9 ft. in height; the layout is shown in Fig. 2. The equipment in this room weighs about 11 tons and comprises:

(*a*) *A Power Control and Distribution Board.*—This board, which is of steel throughout and measures approximately 7 ft. by 5 ft. by 2 ft. 6 in. deep, carries duplicated stop-start motor and alternator control arrangements for the two main motor-alternators (which are seven decks below), together with the necessary pilot lamps, voltmeters, ammeters, frequency meter, and an automatic voltage regulator which keeps the 3-phase a.c. supply at a constant voltage irrespective of the load or temperature conditions. The board also carries the control for the modulating motor-alternator used with the medium-wave transmitter. The 50-cycle 3-phase a.c. supply is distributed to 6 output circuits, each having its own switch and pilot lamp—one to each of the four transmitters, one to the receiving room, and a spare.

(*b*) *A Medium-wave Telegraph Transmitter* [described hereinafter].—This transmitter utilizes five spot frequencies. The transmitter works into a 700-μμF "T" type aerial giving an aerial current of about 21 to 25 amperes on full power, according to wavelength.

A 2-kW motor-alternator used for modulating is mounted beside the transmitter.

The transmitter is mounted on a special shock-absorbing base comprising two heavy channel-iron plinths, one floating elastically on top of the other and allowing universal motion of the transmitter, to protect the valves and control relays against any vibration which might exist.

(*c*) *A Long-wave Telegraph Transmitter* closely resembling the medium-wave transmitter but restricted to C.W. operation, M.C.W. not being permitted on these wavelengths. It utilizes 7 out of the 10 available spot frequencies and works into an "L" type aerial having a capacitance of 2,000 μμF, giving an aerial current of about 25 amperes at full power.

(*d*) *Two Telegraph/Telephone Short-wave Transmitters* [of the type described hereinafter].—These transmitters furnish the two short-wave links of the vessel, one being used normally for communication to Great Britain and the other to the United States. Each has 10 crystal-controlled frequencies between the limits of 3 and 17 megacycles (17 to 100 m.), the frequencies of course being selected so that no mutual interference exists and so that neither the transmitted frequencies nor their harmonics are likely to interfere with reception in the operating room.

These two transmitters stand upon shock absorbers similar to those used for the medium- and long-wave transmitters.

(*e*) *Auxiliary Control Panel.*—An auxiliary control panel is provided at a small desk near the door to the transmitting room. This panel carries switching arrangements allowing of local keying of any of the four transmitters, monitoring any of the receivers in the operating room, and for putting any of the operating room remote-control arrangements completely out of circuit if required, when overhauling the transmitter concerned.

OPERATING ROOM

General Arrangement

The operating room forms the central control point of the entire station, all incoming and outgoing telegraph and telephone traffic being handled here.

Extensive precautions have been taken against interference from the ship's electrical machinery. In addition to the shielding of the receivers themselves, the operating room is lined with copper sheet forming as nearly as possible a closed tank, earthed at one point only to the upper deck. All electrical wiring inside the room is shielded, the shielding being bonded to the copper lining of the room. Every wire entering the room, including lighting, power, telephone, and control lines to the transmitting room, terminates at one or other of several shielded junction boxes, situated in a small compartment immediately external to the copper lining, the main object of this being to ensure that noise brought in by wiring can be rapidly located and the offending lines suitably filtered. All lines from the junction boxes to other parts of the ship are also shielded, the shielding being earthed.

As a further precaution against noise, the ship's d.c. mains are normally excluded altogether from the operating room, and all power for lighting this room, operating the receivers and high-speed apparatus, and battery-charging, is derived from the 3-phase a.c. supply provided by the motor-alternator through a 7-kVA 3-phase transformer situated in the same compartment as the junction boxes mentioned above. The primary of this transformer is mesh-connected and the secondary star-connected, with earthed copper shields between the primary and

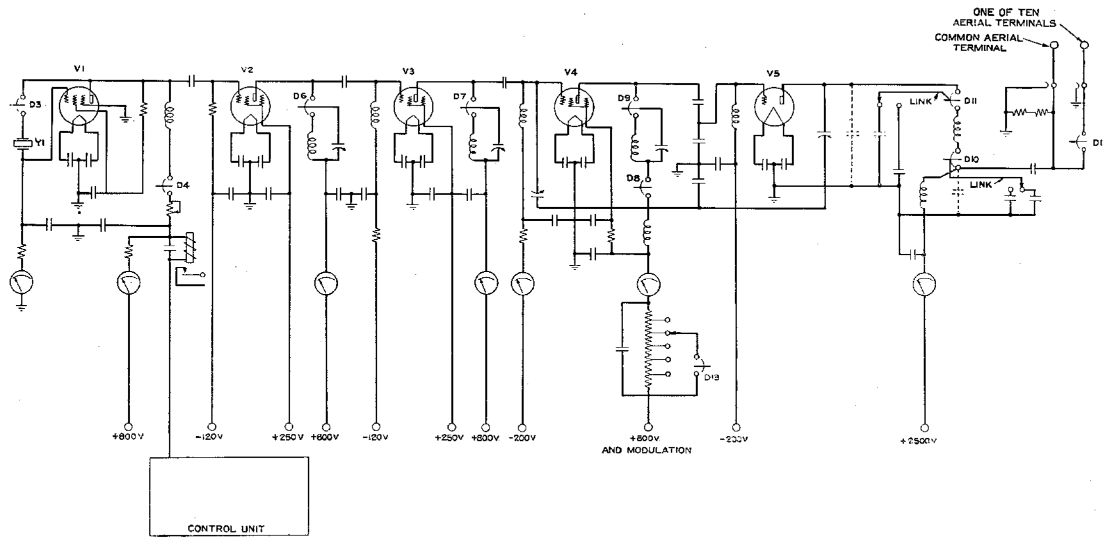


Fig. 3—Simplified Circuit Diagram of Short-wave Transmitter, R.M.S. "Queen Mary."

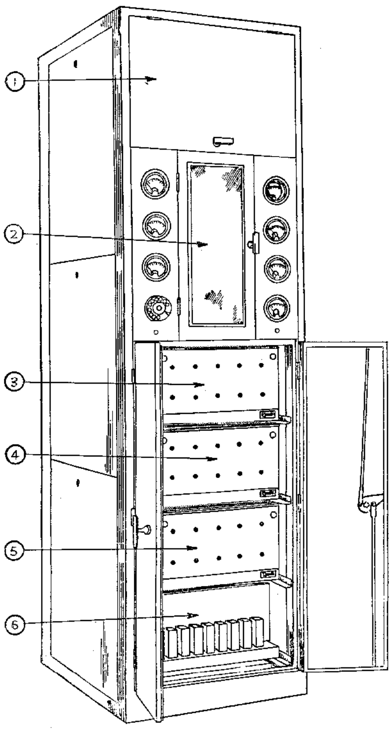


Fig. 4—Radio Frequency Cabinet of Short-wave Transmitter, R.M.S. "Queen Mary."

(1) Output Stage.
(2) Output Valve Compartment.
(3) Modulated Amplifier Stage.
(4) Second Buffer Stage.
(5) First Buffer Stage.
(6) Oscillator Stage.

secondary. The star point of the secondary is also earthed, the three outlets giving separate single-phase supplies used for (*a*) lighting, (*b*) power supply to receivers, terminal equipment and high-speed equipment, and (*c*) battery-charging. The transformer design precludes the possibility of any noise due to the motor-alternator itself reaching the receivers. A change-over switch external to the room allows the lighting system to be transferred to the ship's mains if required, while a second change-over switch allows of an alternative source of a.c. supply for the receivers from a small motor-alternator used for other services on the ship.

Further precautions against noise interference include the fitting of noise suppressors to the four passenger lift motors just outside the receiving room, and to some 200 fan motors ranging up to 10 h.p. on the upper decks, together with the running in earthed conduit of all cables on the upper decks within 200 feet of the receiving aerials.

Operating Positions

The four operating positions are situated at a single bench about 20 feet long and provided with a typewriter well at each position. All telegraphic reception at low speeds (up to 40 words per minute) is carried out aurally, the message being typed out on the appropriate form by the operator. At the side of each typewriter well is a morse key for hand transmission.

All receivers, control units, telephone terminal control equipment, and operators' key panels, are of the rack-mounting type and are mounted in a set of steel cabinets each measuring 3 ft. 4 in. high by 22 in. wide by 12 in. deep, standing at the back of the operating table and facing the operators. Ten such cabinets in all are provided, two to each operating position, plus an extra cabinet between positions 1 and 2 (the short-wave telegraph/telephone positions) and another between positions 3 and 4 (the medium- and long-wave telegraph positions), these additional cabinets containing apparatus common to the positions on either side. The 10 cabinets are bolted together side by side, and are supported by special shock-absorbers to guard the components against vibration. Doors at the back of each cabinet give access for changing valves, etc. The special construction of the panels, known as the "depressed panel system," allows of any repairs being readily carried out after removing the front panels of the cabinets, which are simply cover-plates for the wiring.

Positions Nos. 1 and 2 are identical, each containing a short-wave telegraph/telephone receiver (described hereinafter), the remote control unit for one of the short-wave transmitters, the telephone terminal equipment for one link, and other units as mentioned above. A medium long-wave telegraph receiver is mounted between these two positions, in case either position is required as an additional long-wave telegraph channel. This equipment provides all that is necessary for normal telegraph and telephone communication. Between the two positions is the additional telephone

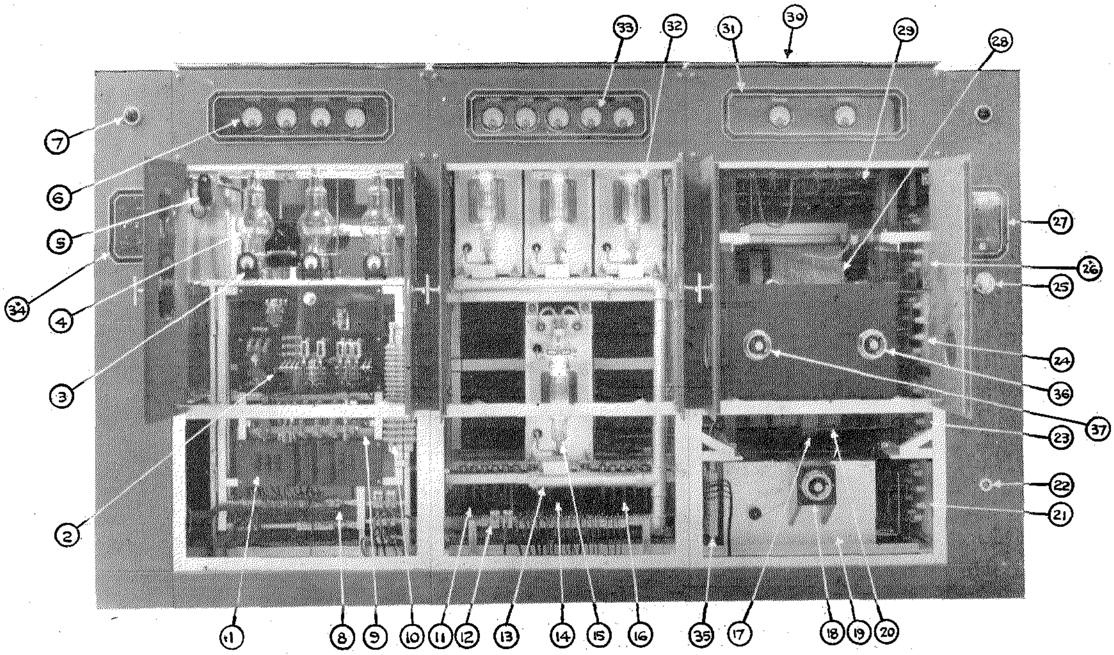


Fig. 5—Front View of Medium-wave Transmitter, R.M.S. "Queen Mary" (Cover Panels Removed).

(1) Rectifier main fuse panel.
(2) Rectifier power-control contactor panel.
(3) Rectifier valve-filament ammeters.
(4) Rectifier valves.
(5) Thermostatic air control.
(6) Rectifier meter panel containing anode ammeters and H.T. voltmeter.
(7) H.T. indicating lamp.
(8) Rectifier main terminal strip.
(9) Main contactor.
(10) Power-control panel strip connectors.
(11) Power amplifier quarter-power resistances.
(12) Valve unit, main terminal strip.
(13) Air supply.
(14) Master oscillator and power-amplifier filament centre-pointing resistances.
(15) Master-oscillator valve.
(16) Power amplifier auto bias resistances.
(17) Aerial coupling coil.
(18) Master-oscillator variometer.
(19) Master-oscillator coil box containing variometer and Selsyn motor.
(20) Amplifier closed-circuit coil.
(21) Master oscillator wave-change switch.
(22) Entry for emergency wave-change handle.
(23) Amplifier closed-circuit wave-change switch.
(24) Aerial coupling-coil wave-change switch.
(25) Wave-change dial.
(26) Aerial tuning-coil wave-change switch.
(27) Wave-change repeater dial.
(28) Aerial tuning coil.
(29) Aerial loading coil (when required).
(30) Aerial lead-out insulator.
(29) Aerial loading coil (when required).
(30) Aerial lead-out insulator.
(31) Aerial and closed-circuit ammeters.
(32) Amplifier valves.
(33) Valve unit meter panel containing master-oscillator and amplifier plate meters and amplifier grid meter.
(34) Local control panel.
(35) Coil unit, main terminal strip.
(36) Aerial tuning variometer.
(37) Amplifier closed-circuit variometer.

terminal equipment allowing either telephone circuit to be put on a "full singing suppressor" basis should communication conditions demand it, the normal condition being only "half singing suppressor." A spare short-wave receiver is also mounted at each of these positions; this is constantly in circuit and is available for immediate use in the event of a valve or other failure in either receiver.

The two privacy equipments, additional singing-suppressor equipment including a delay network, together with their associated power supply rectifiers, are mounted in telephone-type racks bolted to the bulkhead behind the receivers. These are entirely controlled from the two short-wave operating positions and can be cut in or out of circuit as required.

The two short-wave positions, for telephony, normally connect through 2-wire extensions to the ship's telephone switchboard which connects to the 500 cabin staterooms equipped with telephones and to 2-wire phone booths in various parts of the ship, as well as to the ship's official services. In addition, a number of 4-wire extensions are taken to certain of the principal staterooms, through a special 2-wire to 4-wire sub-switchboard at the ship's exchange, to allow of 4-wire working when desirable. In the case of these staterooms, when 4-wire communication is necessary the operator at the ship's exchange disconnects the subscriber from the 2-wire central exchange and connects him direct to the radio terminal equipment on a 4-wire basis. A 4-wire telephone is also provided in a telephone booth near the radio accepting office and is connected directly to the terminal equipment.

Operating positions Nos. 3 and 4 are somewhat simpler, handling only telegraph communication. The general arrangement is somewhat similar to that of positions 1 and 2, except that the transmitter remote controls are situated in the cabinet between the two positions. This allows an operator at either position to control either the medium-wave or long-wave transmitters. Each of these positions carries a medium-wave receiver (500–3,000 m) and a long-wave receiver (1,800–20,000 m). In addition, a spare receiver is carried between positions 3 and 4, for use in the event of breakdown of one of the other receivers.

High-speed Position

Two high-speed tape transmitting keys, together with their associated perforators and a morse undulator, are mounted on a separate table in the operating room. The driving motors of all high-speed apparatus are of the inductor type to avoid commutator noise. Each of the high-speed keys can be connected to operate any one of the four radio transmitters, and can be controlled either locally or from the operating positions.

Satisfactory transmission and reception of messages at speeds of up to 80 words per minute have been carried out with the above apparatus.

Supervisory Position

The supervisor sits at a desk overlooking the rest of the operating positions, his duties being to route accepted telegrams to the proper operating position for transmission, to monitor any of the circuits if required, to keep an additional loud-speaker listening watch on the 600 m wave and on three other circuits, and to perform various circuit-switching duties.

Special provision is made to give the supervisor direct telephone communication with the navigating bridge and with the transmitter room.

Emergency Position

The emergency position resembles the normal equipment of an ordinary cargo ship and comprises (1) an I.C.W. transmitter having three "spot" wave-lengths of 600, 705, and 800 m, and delivering some 4 amperes to the emergency aerial, and (2) a 5-valve receiver covering a waveband of 110–2,000 m. The transmitter is operated through a motor-alternator from a 120-volt emergency battery which also provides H.T. for the receiver. The receiver filaments are supplied from a 24-volt battery, which can also be used in the very last resort to operate the transmitting motor-alternator, which is double-wound for 120 and 24 volts input. The batteries are charged from the a.c. supply through a dry rectifier.

POWER ROOM

The power plant is situated in a small fire-proof compartment adjacent to the ship's engine room, and is in duplicate. It comprises two 45-kVA, 220-volt, 50-cycle, 3-phase a.c. motor-alternators, driven off the ship's 220-volt d.c. mains, with automatic starters remote-controlled from the power board in the transmitting room.

The a.c. supply here generated feeds not only the transmitters, but also all the receivers and terminating equipment; it furnishes in addition the normal lighting supply for the operating room, and battery-charging supply for the emergency equipment.

AERIAL SYSTEM

In designing the aerial system, the principal points borne in mind were that (*a*) both the transmitting and receiving aerials should have the maximum possible efficiency, and (*b*) the transmitters should interfere as little as possible with reception. These conflicting requirements are difficult to reconcile on a small ship, but fortunately the great size of the *Queen Mary*, allowing of comparatively wide separation between the transmitting and receiving points, materially assisted matters.

Fig. 1 illustrates the general aerial arrangement finally adopted. It will be seen that, with the exception of the long-wave aerial, the transmitting aerials are kept to the after part of the ship, and the receiving aerials between the first and second funnels, over the operating room.

The medium- and long-wave transmitting aerials were the easiest to arrange, the requirements being that they should be as high as possible and should have large capacity so as to insure low working voltage and reduce any tendency to brush discharge. Accordingly, twin-wire aerials were provided in both cases. These are suspended between spars at the foremast and mainmast heads, the top spans of the one being shackled to those of the other through insulator chains. The medium-wave aerial is of the "T" type, with top span 150 feet long and a downlead 80 feet long dropped almost vertically to a steel "trunk" (or protective conduit) leading to the transmitter room below. The long-wave aerial is of the inverted "L" type, with its down-lead at the after end leading to another trunk over the transmitting room.

The two short-wave transmitting aerials are of the inverted "V" type, giving an appreciable directive effect. That for one transmitter comprises two inverted V's in parallel, the apices being suspended one from each end of the mainmast spar, the far end of each "V" being taken aft to the docking bridge and splayed out to the sides of the ship. The other aerial similarly consists of two wires, the apices of the "V" in this case being suspended one from each side of No. 3 funnel. A number of tests were carried out during the construction of these aerials to determine the best lengths and angles of suspension for the legs of the "V," both by field-strength measurements on a launch cruising at various distances from the ship, and by simultaneous measurements taken by a number of observation stations in different parts of the world during the trials, with the ship swung at various angles. For the first aerial mentioned above, the following gains relative to a half-wave vertical aerial were observed in the fore-and-aft direction :

Frequency Mc	Gain db
4	0
8	5
13	8
17	6

The major lobe of transmission was approximately 60° wide at 17 megacycles, gradually widening until there was practically uniform coverage at 4 megacycles. It is interesting to note that preliminary tests, using only a single-wire "V" suspended on one side of the ship, showed a displacement of the major lobe by some 20° from the fore-and-aft line of the ship ; this was corrected by adding the second wire. The other aerial has slightly less directivity, but is still markedly superior to a plain vertical aerial.

The results shown above are in accordance with requirements ; during the greater part of the voyage, when the higher frequencies are required, great-circle bearings between the ship and the shore stations in this country and the United States respectively are within 20° of the fore-and-aft line of the ship, and the directive effect is therefore most useful. When the ship is nearing land and requires the 4-megacycle transmission, the great-circle bear-

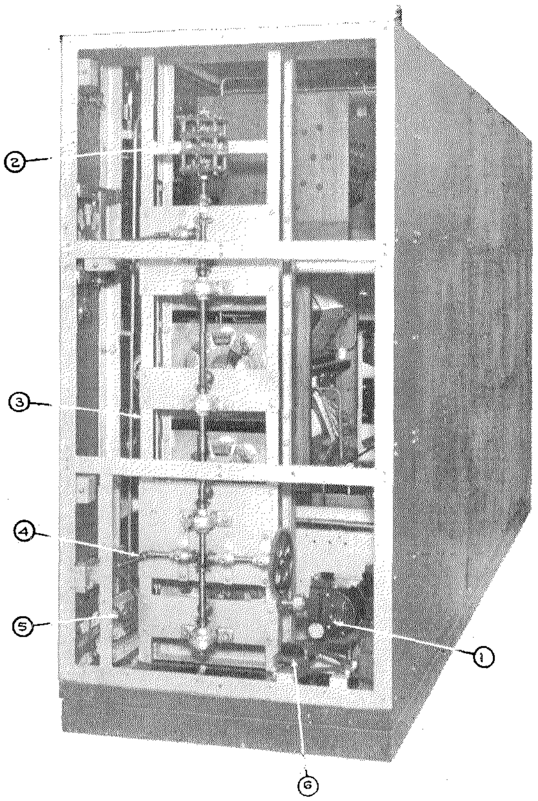


Fig. 6—End View of Medium-wave Transmitter, R.M.S. "Queen Mary" (Cover Panel Removed), Showing Wave-change Gear.

(1) Wave-change Motor.
(2) Control Switches.
(3) Complete Assembly of Wave-change Switchgear.
(4) Hand-control for Emergency Wave-change.
(5) Wave-change Unit Main Terminal Strip.
(6) Wave-change Motor Fuse.

ing from the ship tends to alter considerably and therefore non-directive transmission is preferable.

Four short-wave horizontal-doublet receiving aerials are fitted, known as the 4-, 8-, 13-, and 17-megacycle aerials respectively, though the actual frequency response of each extends considerably on either side of the nominal frequency. The 8- and 13-megacycle aerials, being the most used, are double-doublets to increase the frequency coverage.

From each of these aerials a balanced open-wire transmission line runs down to the top of a trunk above the operating room, and thence through impedance-matching transformers and concentric transmission lines to a switching panel equipped with screened jacks and patch cords, from which in turn concentric cables run to the four short-wave receivers. Any aerial may be connected to any receiver at the switching panel. The use of concentric transmission line is very advantageous in eliminating local interference.

For medium- and long-wave reception two aerials are provided. One of these is of the inverted "L" pattern, suspended between the first and second funnels, and can be switched over to the emergency position in the operating room for use as emergency transmitting and receiving aerial. The other is a relatively short inclined aerial, and is used for reception only, principally for duplexing on long waves and for Press reception. All the medium-wave receivers can be connected to one of the aerials, while all the long-wave receivers can be connected to the other aerial, the connections being made through screened patch cords and jacks and then through a concentric transmission line and rejector circuit. The rejector serves to cut down to a safe value the high voltages induced by the long-wave transmitting aerial which runs directly above the receiving aerials, any residual interference being eliminated in the receiver preselector circuits as subsequently explained.

Finally, a separate aerial is provided for the reception of broadcast programmes. This aerial is quite short (60 feet in length) and runs from No. 1 funnel to the receiving aerial trunk, from whence it is fed, through impedance-matching transformers and a rejector unit, to the high-fidelity receiver mentioned below.

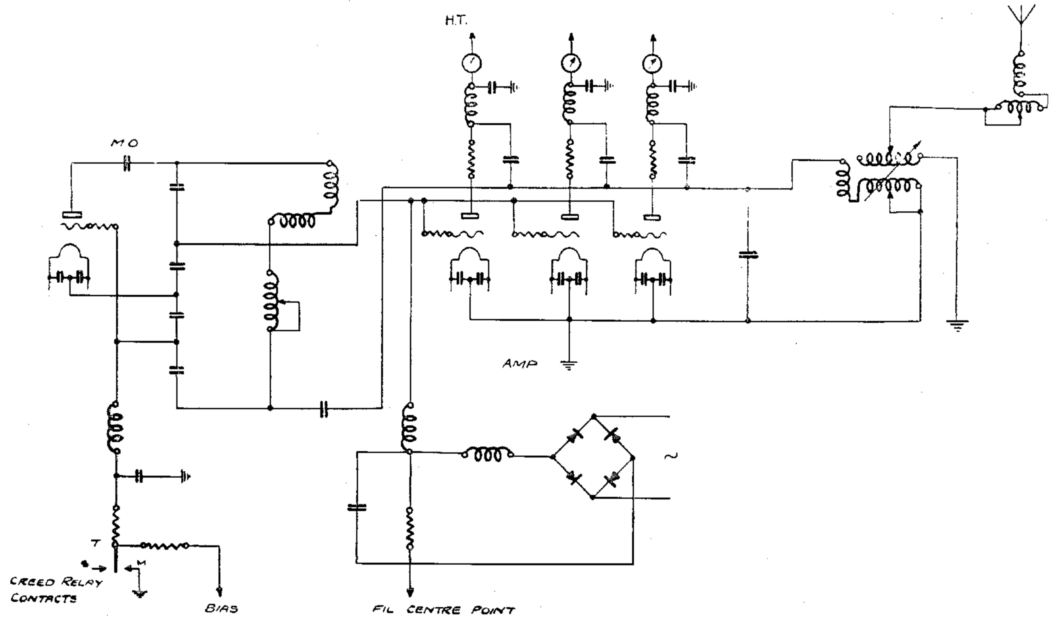


Fig. 7—Simplified Circuit Diagram of Medium- and Long-wave Transmitters, R.M.S. "Queen Mary."

Broadcast reception suffers no interference from the ship's transmission on either short, medium, or long waves.

SHORT WAVE TRANSMITTER (TYPE 14-B)

In the case of the short-wave transmitter the factors chiefly influencing the design are the provision of (*a*) very stable carrier; (*b*) quick change from one spot wave to another; (*c*) moderate output power of approximately 400 watts. The stable-carrier requirement is met by the provision of a separate quartz crystal for each wavelength, followed by five amplifying stages in order to reach the required output level. This involves a number of tuned circuits, each requiring adjustment by tappings or otherwise for each spot wavelength. The use of tappings on short wavelengths is practicable only to a limited degree, and accordingly the wave-change principle embodied in this transmitter is the provision of entirely separate tuning units at each stage for each of the 10 spot wavelengths, the valves being connected to the appropriate tuning units through switches operated simultaneously under the control of a telephone dial. Fig. 3 shows a simplified circuit diagram of the radio-frequency stages with all the tuning units for one wavelength, D1, D2, etc., being the switches connecting the permanent valve circuits to the tuning units. The latter are of plug-in pattern, and are available for a waveband of 16.6–150 m (frequency 2–18.1 megacycles).

The transmitter consists of two cabinets, each of dimensions approximately 24 in. wide, 30 in. deep and 83 in. high, mounted side by side. One cabinet contains the radio-frequency valves and circuits, while the second contains the audio-frequency amplifiers together with the rectifiers and other apparatus. Both cabinets are of the enclosed type with access to apparatus through doors. A ventilating fan is included in the radio-frequency cabinet. The entire equipment is designed to operate from a 3-phase 50-cycle 220-volt source, and has a power consumption of approximately 3.5 kW at full load.

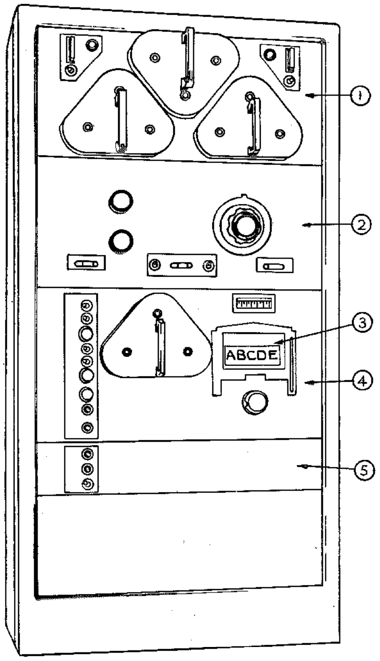


Fig. 8—Rack-mounted Short-wave Receiver used on R.M.S. "Queen Mary" (Waveband 13.5–550 *m).*

(1) Combined Power Panel and Spare Coil Rack.
(2) Preselector Unit.
(3) Five-track Tuning Condenser Scale.
(4) Receiver Unit.
(5) Note Filter.

As can be seen from Fig. 4, the radio-frequency cabinet includes a number of sub-units of chassis construction. Starting from the bottom, these are: oscillator stage, first buffer stage, second buffer stage, modulated amplifier stage, output-valve compartment, and output stage. Each chassis mounts a total of 10 plug-in tuning units, while the bottom chassis in addition mounts up to 10 quartz crystals. Adjustment of any of the tuning units can be performed, while the equipment is in operation, by means of a tool inserted through an aperture in the grounded front cover-plate of the chassis. All the chassis are quickly removable for examination of components, and are automatically disconnected at all terminals as they are withdrawn from the cabinet.

Both the first and the second buffer stages may be used either as straight amplifiers or as frequency doublers, according to the relation between the crystal frequency and the required frequency. For telephony or M.C.W. the modulating voltage is applied in series with the

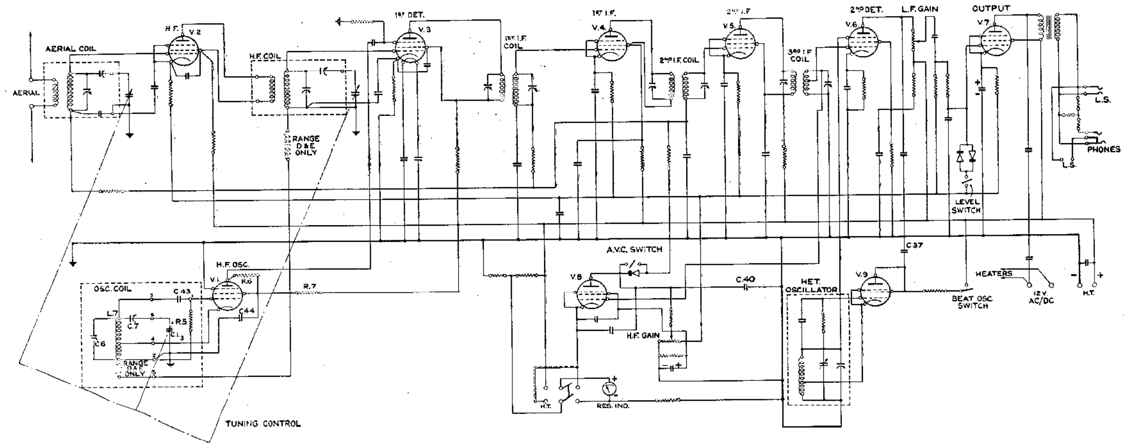


Fig. 9—Circuit Diagram of Short-wave Receiver Unit.

high-tension supply to the penultimate valve, and modulates both plate and screen-grid voltages. Keying is effected at the plate of the oscillator, which is earthed through a key-controlled relay system during the spacing periods. When the transmitter forms part of a radiotelephone link circuit the carrier is, by means of the terminating equipment described later, automatically switched on while the ship subscriber is speaking. In this case the actual switching removes the earth from the plate of the oscillator, as during keying, but the train of relays involved is adjusted so as to provide a short "hangover" period of 150 milliseconds to prevent the transmitter being switched off in the intervals between words.

The wave-change system employed is relatively simple. At the back of the transmitter is a row of 10 vertical rods, one for each wavelength; at the foot of the transmitter is a horizontal shaft equipped with 10 cams which are normally free on the shaft. On dialling the single digit number allocated to the wavelength or "channel," the appropriate cam is locked to the horizontal shaft which then rotates the cam, raising the corresponding vertical rod, the latter operating a number of bell cranks which close switches connecting into circuit the crystal and all the pre-set tuning units for the particular wavelength required. The time required to change wavelength depends almost wholly on the dialling operation, and varies from about 1 to 2 seconds according to the digit dialled. The wave-change system is interlocked with the protective system to remove the high-tension supplies during the circuit change.

The output circuits of the transmitter are designed to work into an impedance of 500 ohms; each output circuit is connected (through a switch forming part of the wave-change system) to its own aerial terminal and also to a common aerial terminal. Each wavelength may therefore have its own aerial directly connected to the transmitter, or alternatively the transmitter may always work into a common 500-ohm transmission line connected to one or more aerials through a separate tuning and coupling unit. In the latter case the coupling unit is equipped with the requisite number of plug-in type tuning circuits, together with a wavechange system of the same pattern as that used on the transmitter, and controlled simultaneously therewith. By means of this arrangement it is possible to use either open-wire or tubular feeders to the aerials, and to use the same aerial on more than one wavelength.

The power supply required for the transmitter circuits is derived from the second or rectifier cabinet. All filaments are heated by alternating current, while three hot-cathode mercury-vapour rectifiers—two of the 3-phase half-wave type and one single-phase full-wave—give the d.c. supplies for anodes and screen and control grid bias. The same cabinet contains a 2-stage audio-frequency amplifier to supply the modulating voltage; this amplifier will give full modulation with an input of 23 db below reference level (5.9 milliwatts). The relay trains used for keying or voice-controlled carrier switching are also fitted in this cabinet, on a removable chassis mounted in the top section.

Remote control of the transmitter is centred on a special panel mounted on the same "operator's position" rack as one of the receivers in conjunction with which the transmitter is used. This remote panel provides for selection of any of the three possible types of communication — C.W. telegraphy, M.C.W. telegraphy, or radio-telephony. It is also equipped with a dial for wave selection, an 800-cycle oscillator to supply tone for M.C.W. modulation, a voltmeter which measures the speech-level supplied to the transmitter (and can be considered as a modulation indicator) and with controls for the depth of modulation, etc., as required for radio-telephone link working (dealt with in a following Section).

MEDIUM- AND LONG-WAVE TRANSMITTERS (TYPE M.20 and 21)

Taking first the medium-wave transmitter, this covers a band of 585 to 822 m with dial-controlled switching to any one of up to 10 spot wavelengths within this band, and aerial circuit power of 3 kW on C.W. or 3 kW plus 80 per cent. modulation on M.C.W. Power input is from a 3-phase, 50-cycle source, with the transformers and any rectifiers required to furnish the various filament, anode, and grid supplies, etc., included in the transmitter. The main H.T. rectifier uses hot-cathode mercury-vapour valves, but all other rectifiers are of the dry metal type.

Views of the general assembly are shown in Figs. 5 and 6. During operation the transmitter is completely enclosed, except for ventilating louvres, cooling being aided by a built-in blower system. Access to the interior is obtainable through doors which, when opened, operate gate switches to cut off the H.T. supply.

The basic circuit of the transmitter is shown in the simplified circuit diagram, Fig. 7. A single-valve self-biased master-oscillator drives a neutralized power-amplifier group of three parallel valves, the output of which is inductively coupled to the aerial through a tank circuit. Keying is performed through a high-speed polarized Creed relay which biases back the grid of the master-oscillator valve. Excellent signal wave-form is obtained up to key speeds of over 100 words per min. For M.C.W. operation the power amplifier is anode modulated by tone derived from a 700-cycle, 2-kW alternator. Provision is also made for low-power grid modulation of the power-amplifier stage, to give either telephony or M.C.W. of other than 700-cycle tone.

The main H.T. rectifier is of the 3-phase half-wave type with one hot-cathode mercury-vapour valve per phase. A spare valve is fitted in position and can be switched as a replacement into any of the three phases; its cathode is kept heated to half brilliancy during the period when it is not in use so as to avoid the serious loss of time otherwise involved in "conditioning" a valve which has been lying idle for some time. When first starting up the transmitter at the commencement of a voyage an automatic time delay ensures that high tension is not applied until the rectifiers are properly warmed up by having their filaments alight for 5 minutes.

The long-wave transmitter is identical in design, power, and facilities, with the medium-wave transmitter, except for the electrical values of tuning condensers, etc., and the addition of an aerial loading coil. It covers a wave-band of 1,875 to 3,000 m, on which, by regulation, transmission is confined to C.W.

As can be seen from the illustrations, the transmitter includes two narrow end-bays flanking three large bays assembled together to form a single unit. The first (end) bay from the left (Fig. 5) contains the air blower, Creed relay equipment, remote-control relay rack, and local-control circuit equipment. In the second bay are housed the main H.T. mercury-vapour valve rectifier with its associated transformers and other power supply gear, together with the dry metal rectifiers for circuit control and grid bias, etc. The third or centre bay contains the master-oscillator and amplifier valves, together with their blocking and tuning condensers, high-

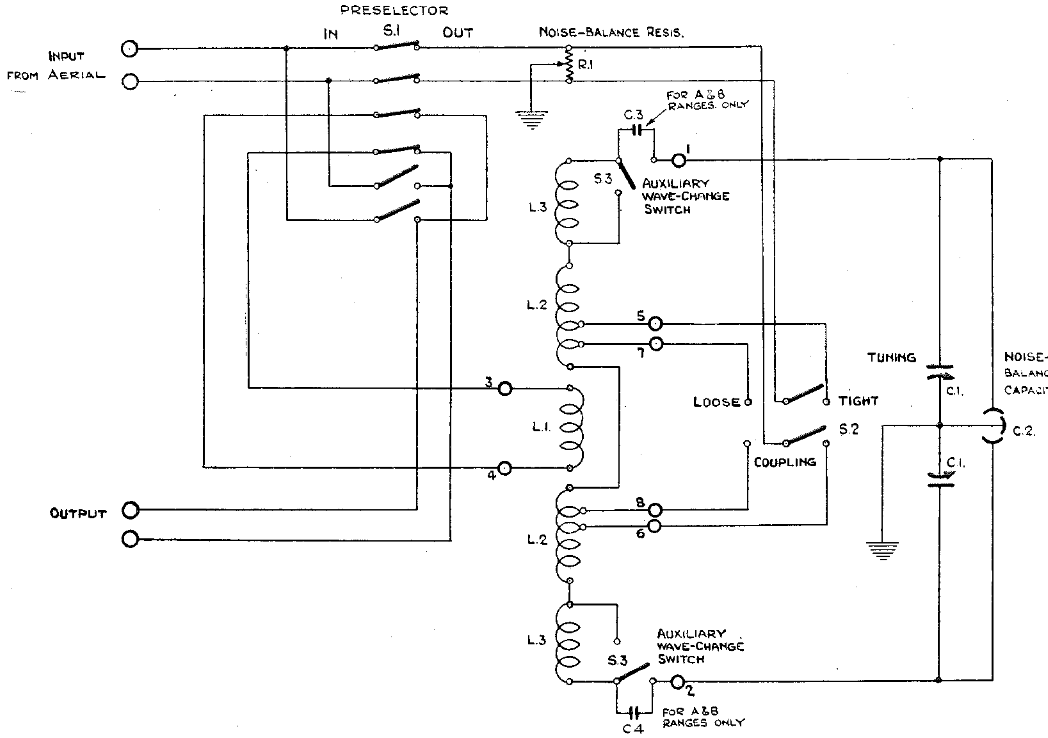


Fig. 10—Circuit Diagram of Short-wave Receiver Preselector Unit.

frequency chokes, and protective resistances. The fourth bay contains all the tuning coils for both master-oscillator and amplifier circuits, together with a remotely-controlled mechanism associated with the master-oscillator tuning circuit. The remaining end bay (Figs. 5 and 6) is devoted to the wave-change mechanism.

The method of wave-change used is as follows. The same tuning coils and condensers remain in circuit on all wavelengths, but the active tappings on the tuning coils are changed. In the case of the medium-wave transmitter there are three tuning coils involved—master-oscillator, power-amplifier output, and aerial tuning; while for the long-wave transmitter there is one additional coil for aerial loading. Associated with, and mechanically close to, each tuning coil is a 10-point rotary switch, whose studs are connected to tappings on the coil corresponding to the desired wavelengths. An unusual feature of the switch is that contact between brush arm and stud is made through a special spring-loaded metallized carbon brush with pigtail connection to the brush carrier, the assembly closely resembling the brush gear used on ordinary electrical machinery. All these 10-point switches are operated simultaneously from a common vertical power shaft to which the rotating brush-arms are individually coupled through bevel gears. This common power shaft is itself driven through reduction gear by a small motor which, when idle, has its rotor clamped by a powerful brake and whose starting and stopping is governed by a telephone dial and relay system on principles similar to those used in the design of an automatic telephone exchange.

In addition to the switches just referred to, another group of four 10-point rotary switches are driven from the vertical power shaft. One of these is a pilot switch connected into the relay circuits to complete the motor-stopping circuits when the switches have travelled to the correct tap-contact position; another ensures that high tension is not applied to the valves unless the h.f. circuits are complete; the third switches auxiliary tuning condensers through a contactor system; while the fourth is used to "indicate back" the position of the switches to the remote-control position.

The common power shaft also furnishes drive to an illuminated indicator disc marked for each position with the frequency and dial number of the wavelength to which the transmitter is then set. In the event of failure of the shaft-driving motor it is possible to operate the shaft through a free-wheel device by means of manual control from the front of the transmitter.

The control circuits are so arranged that if a new wavelength is dialled while the transmitter is running, i.e. with anode H.T. "on," in order to safeguard the valves the H.T. supply is automatically disconnected before there is any movement of the power-driven wave-change group of switches, and is restored when these switches have reached the position corresponding to the number dialled. The time taken to change wavelength depends on the amount of travel of the rotary switches, and in the extreme case of changing, say, from wavelength "3" to wavelength "2," which involves the maximum travel (since the switches always rotate in the same direction, and must therefore traverse 9 positions for the case quoted) this total time does not exceed 10 seconds. For changing in the opposite direction, i.e. from wavelength "2" to wavelength "3" the time is about 2 seconds. The control mechanism embodies a storage feature whereby it is impossible for a second operation of the dial to have any effect unless the changes governed by the first operation have been completed. If the dial is operated to give the same wavelength as that on which the transmitter is already set, there is no movement of the rotary switches, the only effect of the second dialling being a momentary interruption of the H.T. supply. Dialling may be done either on the "local control" dial mounted on the front of the right-hand bay of the transmitter (Fig. 5) or on another dial located at a distance on a remote-control unit.

It sometimes becomes desirable to change a wavelength very slightly from its pre-set value, say by a few hundred cycles, in order to avoid interference with or from other stations working on the same wavelength. To meet this possibility a small auxiliary variometer is included in the master-oscillator circuit, and is varied at the remote control through a "Selsyn" system to give the desired small frequency change, the switch-selected taps and the master-oscillator and other coils being left unaltered. This system consists, in effect, of two small a.c. synchronous-motor mechanisms, electrically inter-connected so that the rotor of the "receiving" end, coupled to the variometer, does not rotate but takes up a steady position corresponding to the hand-controlled position of the rotor at the transmitting end, i.e., on the remote-control panel.

On the front of the left-hand end bay (Fig. 5) are switches of the telephone pattern which operate through relays to give the following controls: "H.T. on-off," "Full, half, or low power," "C.W. or M.C.W.," and "Local" or "Remote" control. This last switch provides for the transfer of all the other switch facilities just mentioned, together with the signalling key and wave-change dial circuits, to a remote-control unit. In the case of the *Queen Mary* this remote-control unit is situated in the operating room 400 feet from the transmitter.

The remote-control unit is of panel type and is mounted on one of the "operators' position" racks in the operating room. It is equipped with a telephone dial for wave selection, wavelength number repeater to indicate the wavelength on which the transmitter is set, and switches for H.T. supply, etc., as on the "local control" position on the transmitter. It also includes the control for the "Selsyn" system, which governs the position of the master-oscillator auxiliary variometer, and permits fine regulation of the transmitting frequency on either side of its normal value.

SHORT-WAVE RECEIVER (RM. 10)

The receiver units from which the *Queen Mary's* equipment is built up consist of the "short-wave" receiver, wave-range 13.5–550 m, primarily used for short-wave telegraphy and telephony; the "medium-wave" receiver, wave-range 500–3,000m, for medium- and long-wave telegraphy; and "long-wave" receiver, wave-range 1,750–20,000m, for long-wave telegraphy. These receivers are all of the rack-mounted type and have the following features in common:

(*a*) Power supplies drawn from an a.c. power unit.

(*b*) Single-control tuning with large indicator drum (8 inch diameter) calibrated directly in kilocycles, the calibration track covering 280°.

(*c*) Auxiliary note filters for heterodyne reception.

(*d*) Auxiliary preselector circuit which can be switched in or out as desired.

(*e*) Output circuits arranged for loud-speaker monitoring, operating a tape recorder for morse telegraphy, and direct feed to the terminating equipment for telephony. For ordinary reception of morse signals a fixed 13-db attenuator is inserted before the headphones, so that both headphones and loud-speaker or tape recorder can be energized simultaneously at their suitable different levels.

Fig. 8 shows a single short-wave receiver mounted on a rack, together with its associated preselector and power supply units, while Figs. 9 and 10 show the circuit diagrams of the receiver and preselector units respectively. The circuit is of the superheterodyne pattern, requiring 9 valves for the following functions; one h.f., 1st detector, separate beating oscillator, two l.f. stages, 2nd detector, l.f. output valve, separate heterodyne oscillator, and separate automatic gain-control valve. This receiver is particularly designed for use on large liners, and possesses accordingly a number of rather special features. These are:—

(1) The short-wave receiving aerials must be so situated as to be as free as possible from the numerous sources of electrical noise which are normally encountered on board such vessels. This in general means that the aerial is at a fairly large distance from the receiver room, and must be connected thereto by a transmission line, which if of the open wire pattern is itself liable to pick up noise. It is therefore necessary to provide special circuits for coupling the receiver through the transmission line to the aerial. In the present case the required coupling circuits are included in a separate preselector panel unit, which serves simultaneously to match the receiver proper to the aerial transmission line, to give extra selectivity against transmissions on a neighbouring frequency, and to give almost complete suppression of medium and long wave voltages picked up by the aerial. It will also give an accurate balance against any noise currents which may be picked up in the transmission

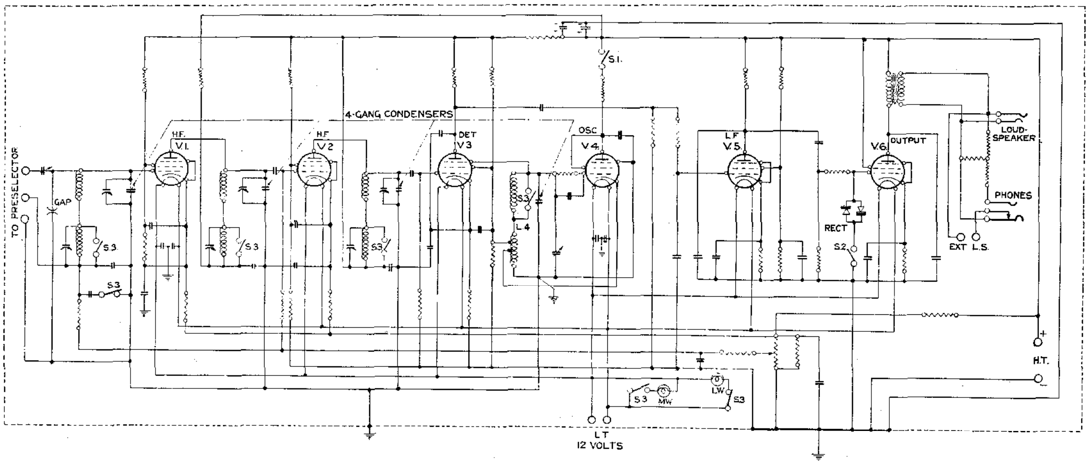


Fig. 11—Circuit Diagram of Medium-wave Receiver Unit.

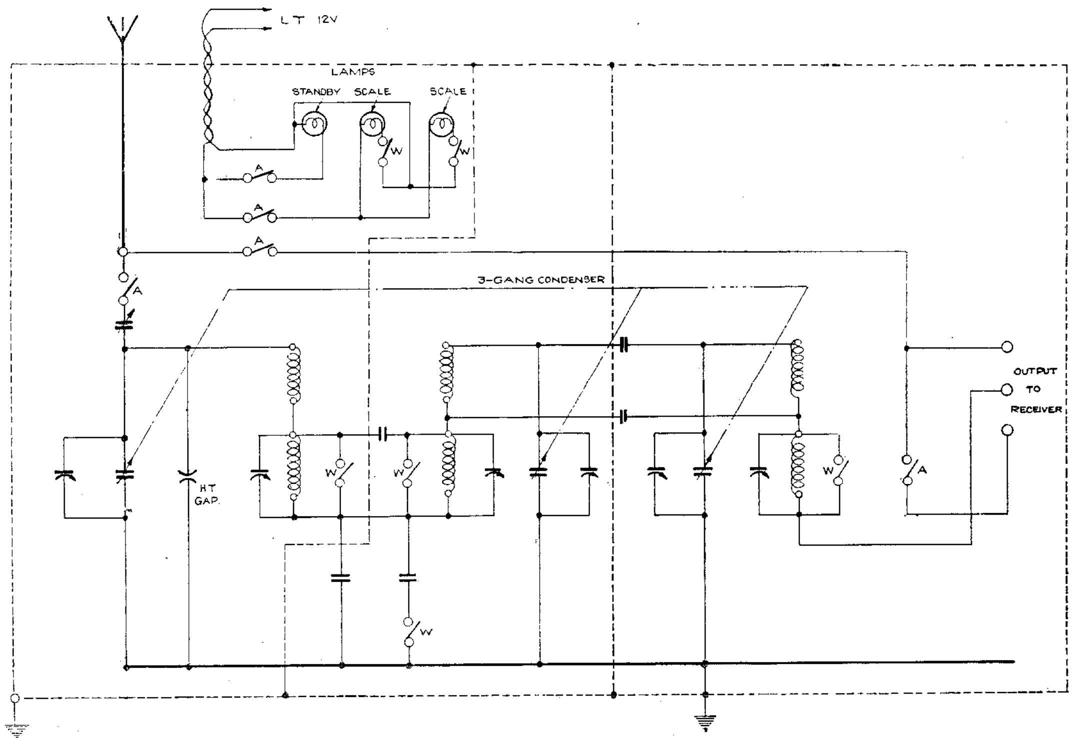


Fig. 12—*Circuit Diagram of Medium-wave Receiver Preselector Unit.*

line if the latter is of the balanced open-wire type.

(2) A single high-efficiency h.f. stage is provided. High efficiency is necessary to ensure that valve noise shall be low compared with the signal, and to give adequate second-channel suppression.

(3) For heterodyne reception with note filter it is necessary that the h.f. beating oscillator remain very constant in frequency. The high-tension supply voltage for the whole receiver is therefore held constant by a "stabilovolt" gas tube, which gives a stable heterodyne note despite changes in the settings of any control other than tuning and also despite large fluctuations in field strength of the incoming signal.

(4) In order to obtain maximum efficiency, plug-in coils are used. Five sets cover the complete wave-range of 13.5–550 m, the range of a set on the shorter wave-lengths not exceeding a 2/1 ratio. Speed and correctness of handling is ensured by ganging each set of coils, while the appropriate directly-calibrated track on the large indicator drum is automatically illuminated when a coil unit is inserted.

(5) The automatic gain control can be set to operate with either of two time-constants, one being symmetrical and suitable for telephony, the other asymmetrical and suitable for telegraph reception. It is extremely efficient, a signal variation of 1 μV to 100,000μV (100 db) of constantly modulated carrier input being stabilized to 8 db variation of audio output.

(6) Tuning is facilitated by a resonance meter operative on either telephony or telegraphy.

(7) An output limiter is provided to attenuate powerful static crashes.

(8) The intermediate frequency is 350 kc, this being the least likely to experience any form of interference during ocean service.

(9) The sensitivity is such that a 30 per cent. modulated signal of 0.5 μV in the aerial transmission line can give at least 50 mW of low-frequency output from the receiver at all frequencies.

(10) The band width is 8 kc for 6 db loss, and 30 kc to 35 kc for 60 db loss.

Medium- and Long-Wave Receivers (RM.11 and RM.12)

The general appearance of the medium- and long-wave receivers is similar to that of the short-wave receiver, except that no plug-in coils are used. The medium-wave receiver covers a waveband of 500–3,000 m in two ranges, with switch selection, while the long-wave receiver covers a waveband of 1,750–20,000 m in three ranges. Both sets are of the straight type, using 6 valves arranged for two stages of h.f. amplification, detector, two l.f. amplification stages, and separate heterodyne oscillator. (The tuning condenser of the heterodyne oscillator is ganged with the other tuning circuits.) Figs. 11 and 12 show the circuit diagrams of the medium-wave receiver and preselector units. Some of the more important considerations affecting the design of both these receivers are as follows:—

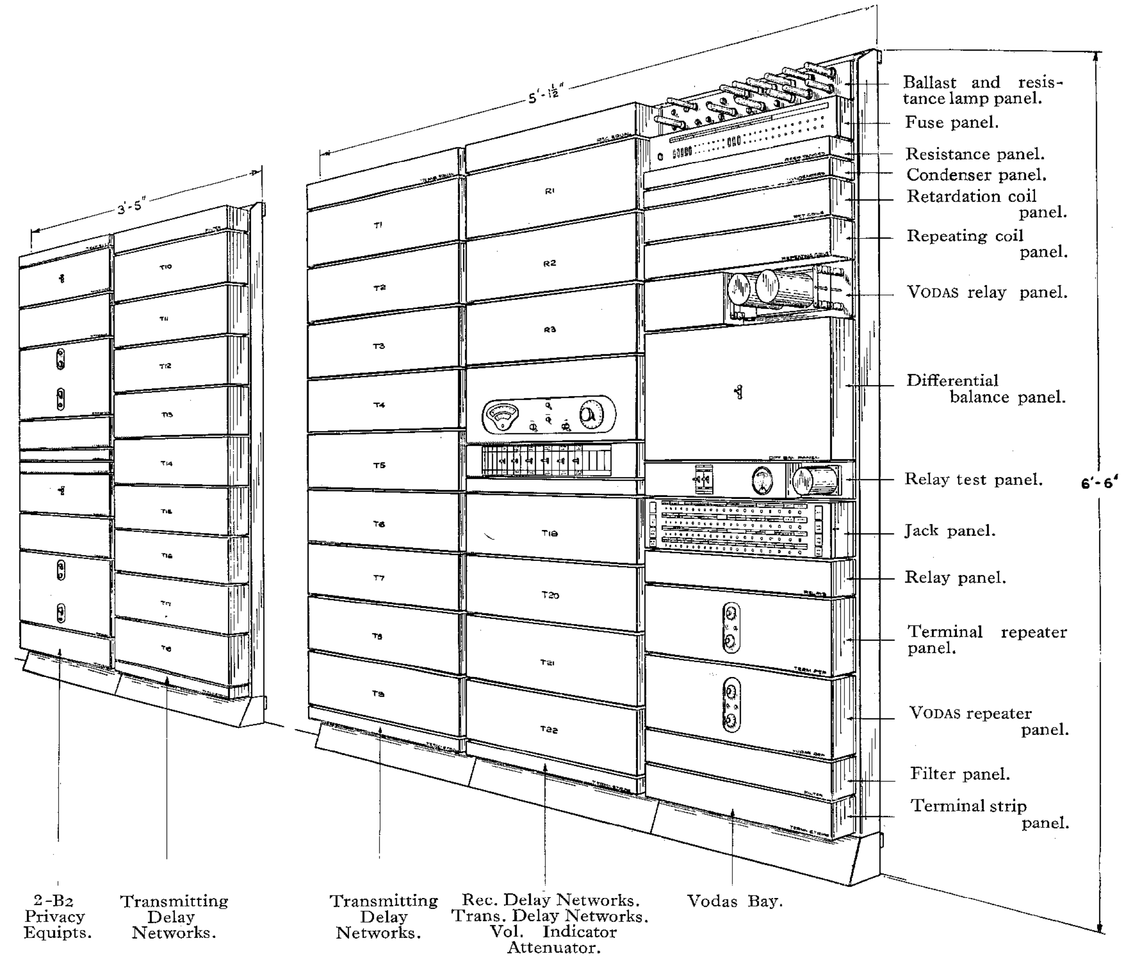


Fig. 13—*Rack Assembly of Terminating Equipment on R.M.S. "Queen Mary."*

(1) The choice of the "straight" circuit is due to the extreme amount of pre-selectivity which is necessary to permit satisfactory medium- or long-wave duplex operation on frequencies differing by less than 10 per cent. In these receivers about two-thirds of the overall selectivity precedes the first valve for duplex operation. Incidentally, as these receivers are used only for telegraphy there is no need that they should pass a definite or constant band width, and note filtering increases still further the effective selectivity.

(2) Both the receiver proper and its associated preselector panel are provided with adjustable input coupling condensers. Following the con-

densers are vacuum-gap arresters set to break down at 1,000 volts in the case of the preselector, and at 500 volts in the case of the receiver. By means of the input condensers the signal coupling can be increased up to the point where voltages induced by the local transmitters become prohibitive.

(3) The preselector units contain three tuned circuits. The first valve is therefore preceded by a total of four tuned circuits, and followed by two others. The preselector units are built throughout with components which can withstand approximately 2,000 volts (r.m.s.) at radio frequency, since the aerial vacuum-gap arresters must not operate continuously and so set up interference to adjacent receivers on all frequencies. Continuous operation of the arresters following the preselector is not usual, and in any case could set up only very small external interference on other frequencies than that to which the receiver is tuned.

(4) When the preselector is thrown out of circuit a lamp is lit to indicate that the band width passed is suitable for stand-by reception. This feature is of special importance for the 600-m watch.

(5) Wave-change switching is provided on both receivers and preselectors, and the correct tracks on the frequency-calibrated indicator drum are automatically illuminated.

(6) "Crash limiting" is provided as in the short-wave receiver.

(7) In order to permit of simplex (break-in) operation on a common wavelength, an overload bias device is provided on the first valve.

(8) The sensitivity of each receiver is such that on C.W. telegraphy the low-frequency output is 50 mW for under 5 μV input. Satisfactory headphone operation is possible with signals of less than 1 μV.

(9) When combined with its preselector, each receiver has a signal frequency selectivity equivalent to an attenuation of more than 100 db at 10 per cent. off signal frequency. The note filter, of course, still further augments the total selectivity.

TERMINATING EQUIPMENT (TYPE T.O.P.5)

With the advent of the subscriber's ship-to-shore radiotelephone service a new item has had to be added to the types of equipment required for ship installation. This new item is the "terminating equipment," which in one form or another is a regular part of all radio-link telephone circuits. The primary function of terminating equipment is to prevent local interaction between the radio transmitter and radio receiver, despite their being deliberately coupled together through the subscriber's apparatus and also unavoidably coupled together by induction from aerial to aerial. In the absence of terminating equipment the effect of these couplings is, in extreme cases, to set up actual "singing" round the circuit, and in less extreme cases to reduce the effective sensitivity of the receiver and to impair the quality of both transmitted and received speech. In addition to preventing this local interaction, terminating equipment may also include some "privacy" system which renders the radiated speech unintelligible to unauthorized listeners.

Although ship-to-shore telephony has been established for some years, it has been customary to keep the terminating equipment down to the minimum consistent with a good speech circuit, and the privacy feature has not been a regular part of the service. In the case of the *Queen Mary*, however, it was considered that the service should be of the same nature as that furnished on the transoceanic links, and the terminating equipment is accordingly not only rather more complete than that hitherto fitted in ships but also includes a privacy system. Since the underlying principles are the same in all cases, the following notes on the *Queen Mary* equipment may be taken as including the main features of the more limited equipment used in older ships.

Fig. 13 shows the rack assembly of the complete terminating equipment, including the privacy portion. Its construction follows normal telephone practice, the only special mechanical feature being in the fixing of the rack to the ship members through a rubber anti-vibration mounting. The privacy portion of the equipment includes five indirectly-heated valves, the remainder, i.e., the terminating equipment proper, using a total of 17 repeater valves of the 0.25 A filament type. All power supplies are derived from the a.c. supply to the station.

The fundamental operation of terminating

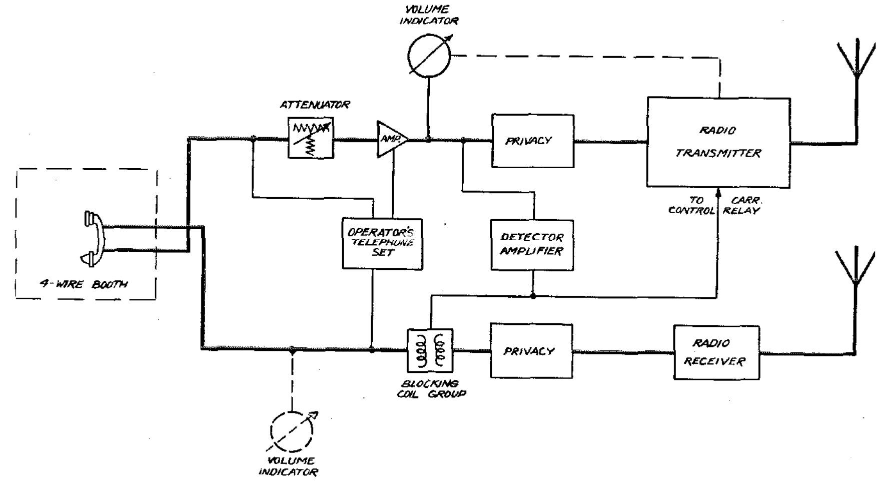


Fig. 14—*Block Diagram of* 4-*wire Radiotelephone Circuit with Half Singing-suppressor Equipment on R.M.S. "Queen Mary."*

equipment is automatic switching of the transmitter carrier, and of the receiver, under the influence of the subscriber's voice, the transmitter being switched "off" and the receiver left "on" at full sensitivity when the subscriber is listening to the distant point, while the reverse action occurs when the subscriber speaks to the distant point. In other words, the radio circuit is effectively operated on a simplex basis, preventing the formation of a "singing path." The switching is performed by means of a voice-operated detector amplifier (see Figs. 14 and 15) operating a fast relay train in the radio transmitter. At the same time as the carrier is switched on, a blocking device is inserted in the receiving circuit so that no singing path can exist (in the case of 2-wire P.B.X. working) round the local loop consisting of hybrid coil, radio transmitter, radio receiver, hybrid coil. The relay train is arranged to have a "hangover" of about 150 milliseconds, i.e. the relays do not release until the lapse of that time after the speech has finished. This prevents any unpleasant echo effects, due to the reflections at the far end, from reaching the speaker.

The voice-operated detector-amplifier controlling the carrier is fitted with a sensitivity control which can be set to suit the conditions existing at any given moment. The sensitivity should be such that the relay train is just operated by the initial weak parts of the speech, and thus "clipping" is prevented. If the sensitivity is made too great, false operation due to room or line noise will occur, causing the local carrier to come on, and cutting off the received speech. After a little experience the operator is able to adjust the sensitivity correctly without any difficulty.

A voice-frequency amplifier and a manually-operated gain control are also provided, so that allowance can be made for varying subscribers' levels. This enables the detector-amplifier to be operated at the correct level and thus prevents possible "clipping," and also enables the modulation of the transmitter to be kept at the correct value.

When the ship's transmitter is setting up a very strong field at the shore receiver, the action of the carrier-suppressor device will cause slight "plops" to be heard by the land subscriber when the carrier comes on, due to the action of the A.V.C. on the receiver. These are not sufficiently loud to be objectionable, but they cause trouble when the circuit is being extended via another radio link. Under such conditions, the transmitting and receiving frequencies must be separated sufficiently to enable the carrier-suppressor device to be removed.

An equipment of the type shown in Fig. 14 is known as a "half" V.O.D.A.S. (voice-operated device, anti-singing) equipment, and covers the essentials in cases where the ship terminal is operated on a 4-wire basis. The usual telephone supervisory and monitoring facilities of course are also provided, but these are purely auxiliary features.

When the ship subscriber is connected in the normal 2-wire manner, additional complications arise, since this means the introduction of a hybrid coil to effect the junction between the transmitting and receiving paths. A hybrid coil is a special type of differential transformer whose windings, in conjunction with the subscriber's line and a balancing network of equal impedance to the line, furnish an a.c. bridge the diagonals of which are connected, directly or inductively, one to the transmitting path and one to the receiving path ; the two paths are thus effectively separated if the bridge is perfectly balanced, although both are connected to the subscriber's line. It is, however, fundamental in the use of a hybrid coil that (the balance between line and network never being perfect) there remains a certain transference of energy across from the "receive" path to the "transmit" path. This is a source of trouble, for two reasons. Firstly, if the received level is allowed to become too high, the fraction of signal which is transferred across the hybrid coil may be sufficient to operate the transmitting detector-amplifier, with consequent re-transmission of the received signal and, in certain circumstances, the setting-up of an undesirable echo at the far end. Secondly, this retransmission may actuate the blocking device in the receiving side, thus cutting off the received signal.

Now, although a good hybrid balance is obtainable on a ship, re-transmission can easily occur if the received signal is fading to a greater extent than the receiver A.V.C. can control. The second effect also occurs if the radio noise-level is very high, since a proportion of this noise will be transferred across the hybrid coil and will cause a similar false operation.

The possibility of such re-transmission occurring is therefore guarded against on the *Queen Mary* by the installation of a full singing-suppressor equipment. This equipment is so arranged that it can be switched instantly into either of the two radiotelephone channels, it being assumed that conditions will nearly always be good enough to allow of one circuit being operated satisfactorily with the half singing-suppressor equipment.

The equipment consists essentially of two

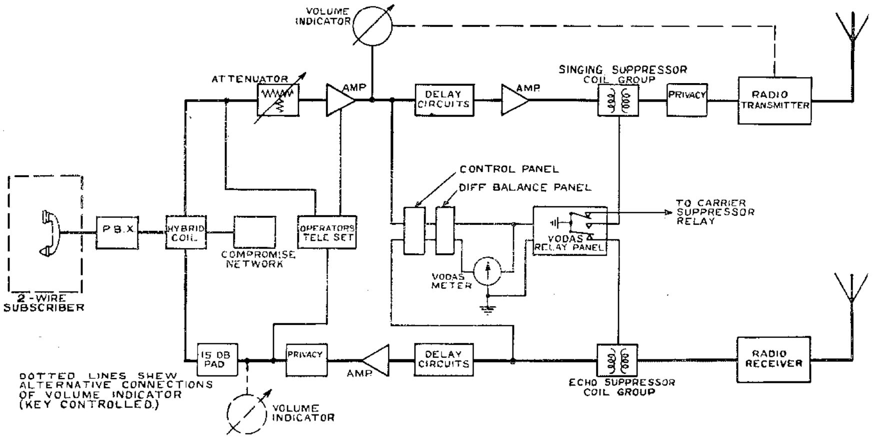


Fig. 15—*Block Diagram of 2-wire Radiotelephone Circuit with Full Singing-suppressor Equipment on R.M.S. "Queen Mary."*

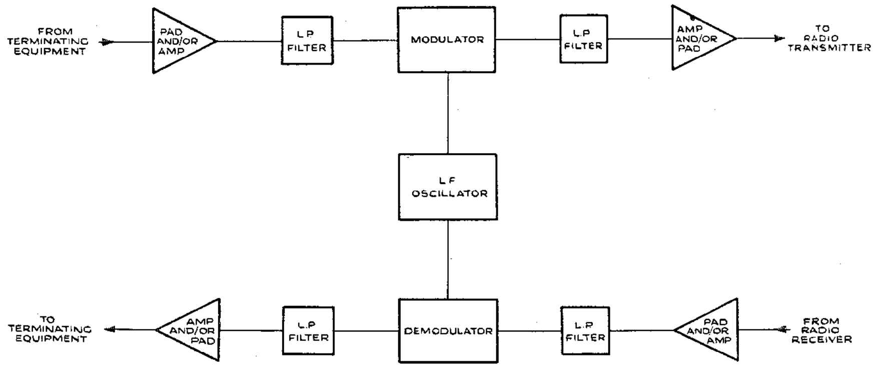


Fig. 16—*Block Diagram of Privacy Equipment on R.M.S. "Queen Mary."*

detector-amplifiers (one in each side of the circuit) with their relay trains and suppressing devices, delay networks to hold up the speech long enough for the relays to operate, and an amplifier to make up the various losses in the circuit. The control of the carrier-suppressor relays is transferred from the original detector-amplifier to the detector-amplifier in the full singing-suppressor when the latter is switched into circuit.

The operation of the equipment (see Fig. 15) is then as follows. Speech from the passenger passes across the hybrid coil and through an attenuator and amplifier. By means of the manually-operated gain control the operator adjusts the passenger's speech to zero level (i.e. 5.9 mW) at the output of the amplifier. The speech then passes through a number of filter sections, so designed that they produce a delay of 22 milliseconds in the speech, irrespective of frequency. These delay filters have a loss of approximately 30 db and are followed by a further amplifier to make good this loss.

Bridged across the main circuit ahead of the delay filters is the transmitting detector-amplifier, of input impedance such that it introduces no appreciable loss. This detector-amplifier takes a small part of the speech currents, amplifies them in a 3-stage amplifier, and then rectifies them. The resulting direct current is used to operate a train of three very sensitive polarized relays mounted on anti-vibration pads. Operation of these relays opens the transmitting path to the outgoing speech, blocks the receiving path, and switches on the carrier in the same manner as in the half singing-suppressor system. The circuit is so arranged that the delay introduced by the special networks also covers the switching-on of the carrier, rendering the possibility of "clipping" still more remote than in the case of the half singing-suppressor, where freedom from "clipping" is governed by the sensitivity of the detector-amplifier and the "quick-starting" properties of the radio carrier.

Consider now incoming speech being received on the ship. This passes through the receiving side of the singing-suppressor and in doing so operates the receiving detector-amplifier, which paralyses the transmitting detector-amplifier so that any speech being transferred across the hybrid coil does not operate it. The existence of the receiving detector-amplifier thus renders it possible to work the circuit on a 2-wire basis when the hybrid unbalance and the noise-level would otherwise make it impossible. The two detector amplifiers, transmitting and receiving, are made up as one unit known as the "differential balance panel."

The full singing-suppressor equipment is set up to work at zero equivalent (i.e., introducing neither gain nor loss) on both sides, so that its insertion or removal does not disturb the circuit.

The circuit is, of course, permanently monitored by the operator, who has a volume indicator in front of him which enables him to check outgoing and incoming levels, both of which can be adjusted by controls conveniently located. In addition, by the operation of a switch, the volume indicator acts as a modulation meter connected to the output of the radio transmitter so that the operator can occasionally check that the modulation depth is remaining at the correct average level. When the full singing-suppressor equipment is in use, an additional meter indicates that it is working satisfactorily. This meter, which is a centre-zero galvanometer, deflects to the right on outgoing speech and to the left on received speech.

Provision is made for the operator to talk either to the ship subscriber or to the distant operator, or to both simultaneously. He also has ring-back facilities to the ship subscriber. For the initial lining-up of the circuit the operators' control positions are equipped for either C.W. or M.C.W. telegraph operation as alternatives to speech. A special "weighted" amplifier, i.e., one whose frequency response curve instead of being flat is adjusted to resemble that of the human ear, is provided for measuring signal/noise ratios ; its gain control is calibrated directly in decibels.

The whole of the voice-control equipment, with the exception of the controls which are located at the receiver control positions, is mounted on four 6-feet single-sided racks carrying standard 19-inch panels (Fig. 13).

PRIVACY EQUIPMENT (TYPE B.2)

The privacy portion of the terminal equipment is, in the case of the *Queen Mary*, supplied in duplicate so as to provide for two simultaneous radiotelephone channels. The two equipments are mounted on a common rack, the layout of which is shown in Fig. 13. The principle of operation (see Fig. 16) is to invert the speech at the sending end so that low frequencies become high, and vice versa, the speech being re-inverted at the receiving end. This inversion is obtained by modulating the speech with a fixed frequency lying outside the voice range, and then selecting by filters the appropriate sideband.

The system is operated on a 4-wire basis, i.e., a separate modulator, together with its associated amplifiers and filters, is used in each direction of transmission. A constant-frequency oscillator supplies the necessary carrier to the modulator and demodulator in the two sides of the circuit, the three units being combined in practice into an "oscillator-modulator" panel. In addition to this panel there is an amplifier, a filter panel, and a mains supply panel. The amplifier enables the privacy equipment to be operated at zero equivalent, while input filters limit the voice frequency range to 2,750 cycles, and output filters cut out unwanted higher modulation products.

The insertion of the privacy equipment is controlled by two keys, one for the transmitting side and one for the receiving side, so that the system can be used in either or both directions of transmission as required. At the same time as the transmitting inverter is switched on, an a.c. motor in the transmitter is started up. This motor drives a subsidiary tuning condenser, which causes the carrier frequency to "wobble" through a certain predetermined band width ; without this "wobbling" it might be possible for speech to be received, despite the inversion, on a simple heterodyne receiver.

PERFORMANCE OF STATION

The results obtained under the heavy traffic conditions of her maiden voyage fully justified the elaborate equipment with which R.M.S. *Queen Mary* was fitted. The simultaneous demands made by telegraphy, telephony, and broadcasting, kept the four transmitters and at least four of the receivers in continuous operation for the greater part of the time she was at sea. Without the independent operation of several lines of communication, rapid wave-change, and automatic transmission, it would have been quite impossible to handle the traffic that was presented.

The results have shown that in spite of the difficulties peculiar to ship installations of this character, by careful engineering a good approach can be made to the operating efficiency of a large land station, where normally the transmitting and receiving sites are some distance apart, and where space is available for extensive aerial arrays.

Condenser Cones for Cable Testing

By J. K. WEBB, M.Sc., A.M.I.E.E.,

Standard Telephones and Cables, Limited, London, England

SINCE the inception of the Condenser Cone as a practical solution of the cable termination problem some three years ago, the use of this device has steadily increased. It now finds widespread application in three distinct categories:

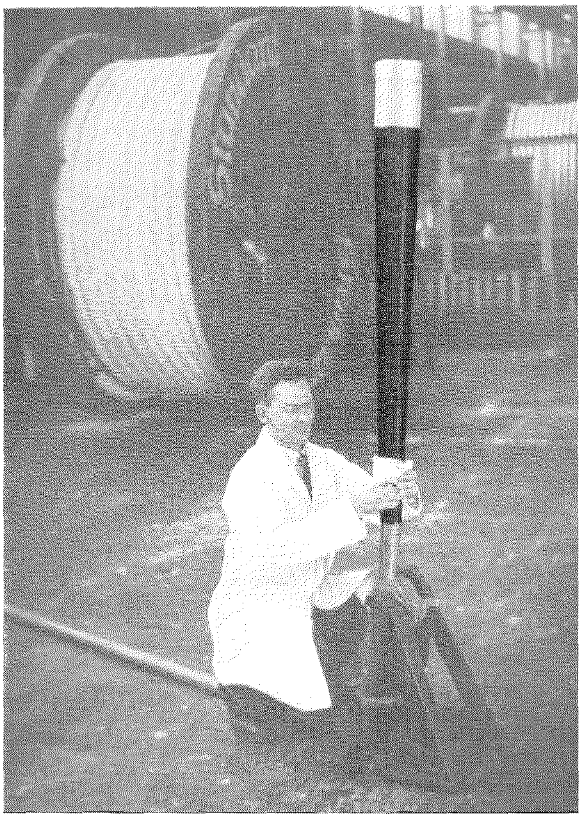


Fig. 1—Mounting a 50-inch Cone on a Cable End. The Cone should be adjusted by gripping with Rag near its Base as shown, and should not be pressed down from the Top.

(i) For the electrical testing of cables in the factory or the laboratory, the ends being in air.
(ii) Under general service conditions, for the potential grading and, hence, strengthening of cable terminations in endbells or boxes.
(iii) For use in joints, to grade leakage surfaces.

In end boxes, as in case (ii), cones have been successfully used to provide capacitative leakage to the high voltage conductor to operate protective relays, and they may also be adapted as carrier current coupling condensers for communication purposes.

A general description of the Condenser Cone has been given[1] and it is sufficient now to say that it has proved both economical and effective in practice. The present article is solely concerned with the use of cones for testing cable ends in air, Fig. 1, since this case involves special problems which have only been overcome by further development work.

For the successful operation of condenser cones under such circumstances, there are three distinct conditions which must be satisfied from the user's point of view:

(i) The length of the cone should be adequate to avoid external flashover. The maximum test voltage is approximately proportional to this length and may be estimated from the values given in Table I. These values, on which there is a certain factor of safety, refer to standard cones under average conditions, and the assumption is made that the cable to which the cones are attached is quite sound. Poorly impregnated or deteriorated cables are liable to initiate surges along their lengths, thus lowering the flashover value. In these doubtful cases, proportionately larger cones should be used.

TABLE I

Total Length of Cone, Inches.	Flashover Voltage kV.
16.5	90
25	140
50	270

It has been found quite practicable to connect two or more cones in series, one above the other, with the inner former of the upper cone connected to the outer foil of the lower cone. In this case, the total flashover voltage of the combination is only slightly under the sum of the separate flashover voltages. This method results in a smaller overall diameter than when a single cone is used, but requires rather longer preparation. It should be noted also that, with two cones, the voltage between the conductor and former of the upper cone is about half of that in the case of the lower cone. The arrangement is illustrated in Fig. 2.

(ii) The radial thickness of the insulation between the inner former and the outer foil on the cone must be sufficient to withstand the test voltage. In general, oil-impregnated cones to standard design will withstand indefinitely the test voltage set out in Table I, so that they may be used over and over again, provided that they remain dry and are normally stored immersed in cable compound. The cones, accordingly, are supplied in specially designed tins filled with compound; they are attached to the lid of the tin, and thereby remain suspended during transport. This system is also convenient for the removal of the cone for test. Fig. 3 illustrates these features.

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[1] "The Condenser Cone," by J. K. Webb, *Electrical Communication*, October, 1933.

(iii) The filling compound must withstand the stress resulting from the test voltage. The compound is most frequently the limiting factor in over-voltage tests, and it is mainly the purpose of the present article to show how this difficulty may best be overcome. This subject has already been briefly referred to in a previous publication[2] but a recapitulation with further details will now be given in order that the subject may be adequately covered.

The stress on the filling compound is greatest at the base of the cone and is equal to the radial stress at the outside of the cable (*i.e.*, *minimum* cable stress) multiplied by the ratio of the permittivities of the cable paper and filling compound. If ordinary cable oil is used, this stress must be kept below about 9 kV/mm., a figure which corresponds with the normal breakdown value of the oil. Cable oil has a permittivity of 2.3 while that of the cable dielectric is 3.8, so that the stress on the oil will be 1.65 times the minimum cable stress at the voltage considered. Thus the use of ordinary oil for filling cones is normally limited to those cases in which this minimum cable stress does not exceed a value of about 5.5 kV/mm. Referring to Table II, this value is seen to correspond to voltages of 3 to 4 times the working voltage depending on the cable design.

TABLE II

Rated Voltage kV. (3 phase)	Radial Thickness of Dielectric in Inches.	Section of Conductor in Square Inches.	Maximum Working Stress kV/mm.	Minimum Working Stress[3] kV/mm.	Working Stress at Surface of Added Roll Increasing Cable Diameter by 50 per cent.
33	.325	.25	3.3	1.67	0.7
		.75	2.91	1.86	0.653
66	.650	.25	4.16	1.41	0.685
		.75	3.45	1.61	0.703

A reduction of the stress on the oil may be achieved by building up the radial thickness of solid insulation in the vicinity of the base of the cone which must then be of diameter large enough to slip over the added insulation. This building up may be effected with impregnated tapes or a continuous paper roll. There should be chamfers between the ends of the roll and the original cable insulation as illustrated in Fig. 4, and an earth screen made up, say, of lead wire or foil wrapped tightly over the lower chamfer and extending for about 1 inch over the parallel portion. Since in this case the cone will be large enough to slip over the lead sheath, the amount of the latter which should be removed for the cable end equals the length of the inner cone, plus 1 inch, plus the length of chamfer.

This building up of insulation, if skilfully carried out, often effects a considerable improvement in the general characteristics of the end. There is always a risk, however, of leaving an air space between the added roll and the cable dielectric, to avoid which both care and experience are necessary. The best thickness of paper for the roll is 5 mils, and it is advantageous to have the inner end of the paper bevelled. With some practice this may be achieved by tearing. Suggested dimensions for these rolls are given in Table III. There

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[2] "Recent Developments in connection with Joints and Terminations"—T. R. Scott and J. K. Webb, *Conférence Internationale des Grands Réseaux Electriques à Haute Tension—Session* 1935, *No.* 209.

[3] The minimum stress in kV/mm is calculated from the formula,

$$S_{MIN} = \frac{E}{R_1 \times 2.3 \log_{10} \frac{R_1}{R_0}}$$

where E = Voltage in kV. between conductor and lead sheath.

R_1 = Outer radius of dielectric in mm.

R_0 = Conductor radius.

may be a case for using impregnated textile tape instead of paper rolls in this connection since, although it is not as strong electrically, it will tend to minimise the risk of air occlusion. Comparative tests, however, have not yet been made.

The increase in cable diameter effected in this way may normally be anything up to 50 per cent. and should not be more than 75 per cent., otherwise difficulties in handling will be experienced with the rolls, but no very rigid rules can be given. Each case must be considered on its own merits. The reduction of stress obtained in this way may be deduced from Table II.

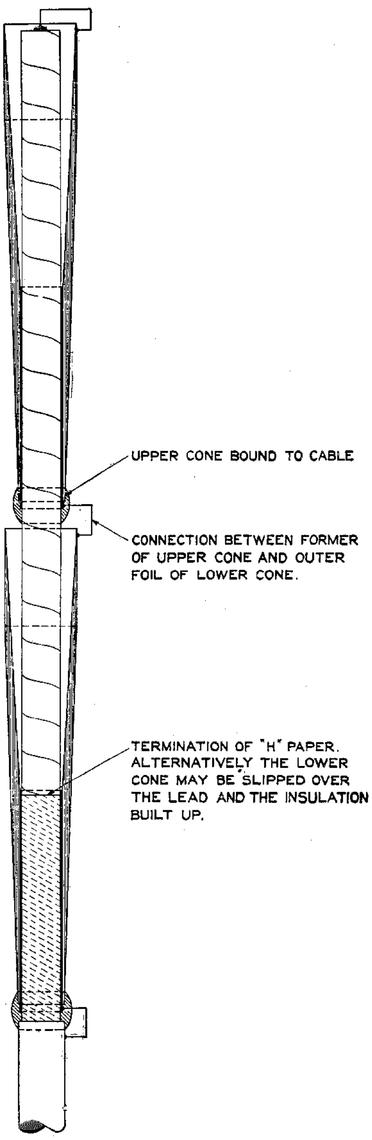

UPPER CONE BOUND TO CABLE
CONNECTION BETWEEN FORMER OF UPPER CONE AND OUTER FOIL OF LOWER CONE.
TERMINATION OF "H" PAPER. ALTERNATIVELY THE LOWER CONE MAY BE SLIPPED OVER THE LEAD AND THE INSULATION BUILT UP.

Fig. 2—Two Cones in Series on a Cable End. As the Upper Cone absorbs half the Voltage Drop, the Stress in the Filling Compound of this Cone is proportionately less than in that of the Lower Cone.

In the case of old, dry or gassy cables or lengths which have been subjected to bending tests, especial difficulty is often experienced with the ends. This is due to the films of gas ionising under the action of the radial stress, and so forming a longitudinal conducting path from the end of the cable core to the lead sheath. It should be borne in mind that a longitudinal stress must always exist at a cable termination; the condenser cone simply gives a uniform gradient to the stress. When failure occurs in such an end, dendritic markings are often found between paper tapes on the cable several layers down. The only satisfactory way of dealing with these cases is to remove the lead sheaths for more than the normal distance, unwind several layers of the cable paper without tearing them, and re-smear each with oil on rewinding. In this way the strength of the end may be greatly improved without affecting the cable characteristics. Prevention, however, is better than cure; therefore in making bending tests, the ends should be handled as little as possible, and precautions taken to prevent movement of paper relative to copper at the extremities.

TABLE III

Length of Cone Inches.	Total Length of Added Roll Inches.	Length of Chamfer Inches.
16.5	6	1.5
25	9	2
50	12	2.5

Since the stress on the oil used for filling is a function of its permittivity, it is to be supposed that raising the value of this constant would have a beneficial effect; and, provided it can be done without causing other factors to obtrude, it has been found to be the case within the limits of materials available. Certain substances, notwithstanding, such as Aroclor, which appear to have everything in their favour, have proved curiously disappointing.

There is, however, another method which has been found to effect a very substantial improvement; it consists in purposely giving the filling compound a high power factor. As the underlying principle may not be obvious, the following explanation may help to make it clear.

Referring to Fig. 5, C_1 and C_2 are two capacities in series, and an alternating voltage E is applied to both. This voltage will divide into two parts e_1 and e_2 depending on the ratio of the admittances of C_1 and C_2. Now if a conductance G_1 is placed across C_1 it is evident that as this conductance becomes infinite, it will short circuit C_1 and hence the voltage e_1 will vanish, while the whole of E will be thrown across C_2. For intermediate values of G_1 it can be shown that

$$\frac{e_1}{E} = \frac{1}{\sqrt{\frac{C_1^2}{C_2^2}\,Cosec^2\,\Phi + 2\frac{C_1}{C_2} + 1}} \qquad (1)$$

$$\text{where } \cot\Phi = \frac{G_1}{wC_1} \qquad (2)$$

$$w = 2\pi \times \text{frequency}.$$

For the particular case in which $C_1 \gg C_2$ the current is practically constant for all values of G_1 and

$$\frac{e_1}{e_2} = \frac{C_2}{C_1}\,sin\,\Phi \qquad (3)$$

In the case of the condenser cone, C_1 represents the capacity of the filling compound, and C_2 that of the cable dielectric in series with it, as illustrated in Fig. 6. The stresses S_1 and S_2 at the surface of discontinuity between these two are proportional to e_1 and e_2, respectively, while C_1 and C_2 are proportional to the permittivities k_1 and k_2. Thus:

$$\frac{S_1}{S_2} = \frac{k_2}{k_1}\sin\Phi \qquad (4)$$

If the filling compound has substantially zero power factor then $sin\ \Phi = 1$ and equation (4) reduces to the well-known form:

$$\frac{S_1}{S_2} = \frac{k_2}{k_1} \qquad (5)$$

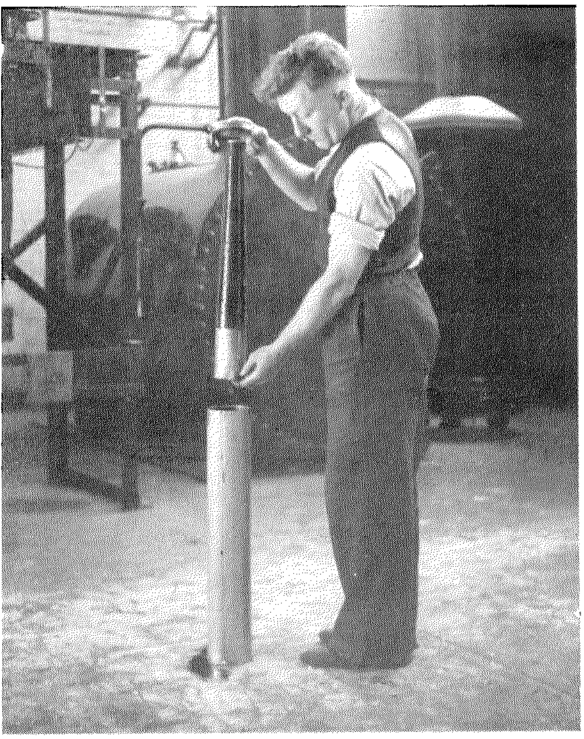


Fig. 3—Withdrawing a 25-inch Cone from its Packing Tin in which it is immersed in Compound. Note how the Cone is attached to the Lid of the Tin.

As the power factor (*cos* Φ) of the compound increases, however, *sin* Φ decreases, and so the stress is transferred from the latter to the cable dielectric which is better able to withstand it. In the limit, if all the stress were thus thrown back on the cable it would still be no greater than in the main body of the cable under the lead sheath. *Sin* Φ is thus the reduction factor which gives a measure of the stress transferred. Its well-known variation with *cos* Φ is illustrated in Fig. 7.

Fortunately enough, compounds of high power factor are usually allied with those of high permittivity; and, moreover, desirable values may be obtained without any appreciable sacrifice of dielectric strength or *B.D.V.*

As a single example, nitrobenzene has a permittivity of 34 and a power factor (*cos* Φ) of over 0.98 at room temperatures. Despite these extreme values, however, its breakdown value is of the same order as cable oil.

It is not suggested that nitrobenzene would be a suitable compound for filling cones. There are two main objections: the first is

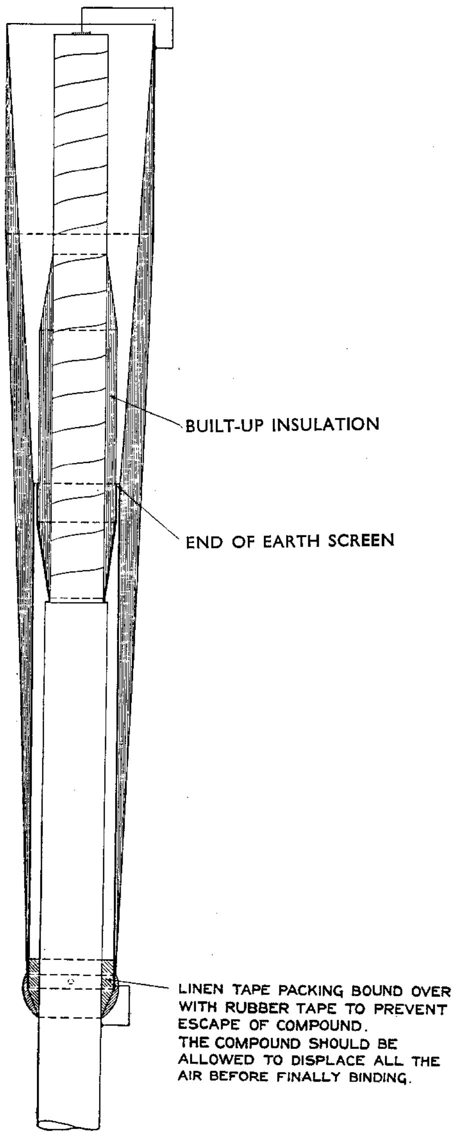

BUILT-UP INSULATION
END OF EARTH SCREEN
LINEN TAPE PACKING BOUND OVER WITH RUBBER TAPE TO PREVENT ESCAPE OF COMPOUND.
THE COMPOUND SHOULD BE ALLOWED TO DISPLACE ALL THE AIR BEFORE FINALLY BINDING.

Fig. 4—Built-up Insulation on Cable End combined with Cone. This strengthens the End, and may be used in conjunction with Ordinary Cable Compound or with Special Compound to attain the Highest Voltages.

that it has an inconveniently low viscosity, so that there would be considerable risk of its penetrating the cable where its characteristics would then be objectionable; and the second is that its power factor is so high that the longitudinal stress which must always exist at a cable end would cause undue heating. It also has a rather objectionable smell and is slightly toxic.

If a thin compound can be tolerated, Halowax Oil has been found to give good results. This material has a permittivity of 4.91, a *B.D.V.*[4] of 25 kV, and a power factor of 0.67 at 20° C. rising to 0.93 at 60° C. Its viscosity, however, is only 3.99 centipoises at 20° C.

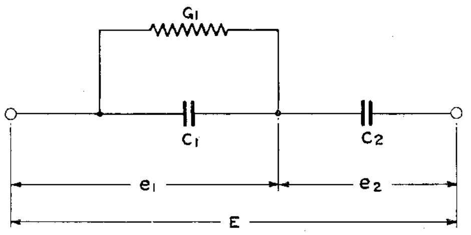


Fig. 5

It might be thought that the losses generated in all compounds of high power factor would give rise to a condition of thermal instability, but in practice this has not been found to occur if the limits are correctly chosen. As the temperature of the compound rises, the consequent elevation in power factor so redistributes the stress that a condition of equilibrium is attained while the compound is still only slightly warm. Occasionally excessive heating occurs at the end, usually when testing old and gassy cable, but it is due to the heat generated in the ionised gas films between the paper tapes.

The main difficulty in producing an altogether satisfactory compound has been to combine a suitably high power factor with high viscosity. Since the former is due to the presence of polar molecules, any attempt at raising the viscosity usually results in a sharp decrease in power factor, and considerable research has been involved in balancing effectively these two opposing factors.

Two compounds have, however, been evolved which appear to be satisfactory. The first (coded as "C.C.8") has the consistency of cable compound and is odourless, non-toxic and clean to handle. It is used for making short time breakdown tests on cable samples where the applied voltage may be anything over three times the working voltage.

---

[4] The break down value (B.D.V.) of compounds referred to in this paper is in accordance with the B.E.S.A. specification (4 mm. gap).

Electrical and physical characteristics are given in Table IV. The permittivity is 5.82 and the *B.D.V.* is 38 kV. Moreover it will only mix with cable mineral oil to the extent of 1 per cent. at 20° C. and 3 per cent. at 60° C.

TABLE IV

C.C.8 (Liquid Compound)

Temp. °C.	Power Factor Cos Φ at 50 p : s.	Viscosity Centipoises.
20	0.32	550
30	0.47	220
40	0.63	114
50	0.79	68
60	0.90	45

so that there is little risk of its penetrating the cable, or influencing in any way the characteristics of the latter in the course of even a fairly prolonged test.

The second compound is coded as "C.C.11." At room temperatures it is a thick, clear and plastic material. On heating to a temperature of about 150° C., it becomes sufficiently fluid to enable it to be poured into the cone; on cooling a glossy film forms on the surface from which dust may easily be brushed. The electrical characteristics are given in Table V.

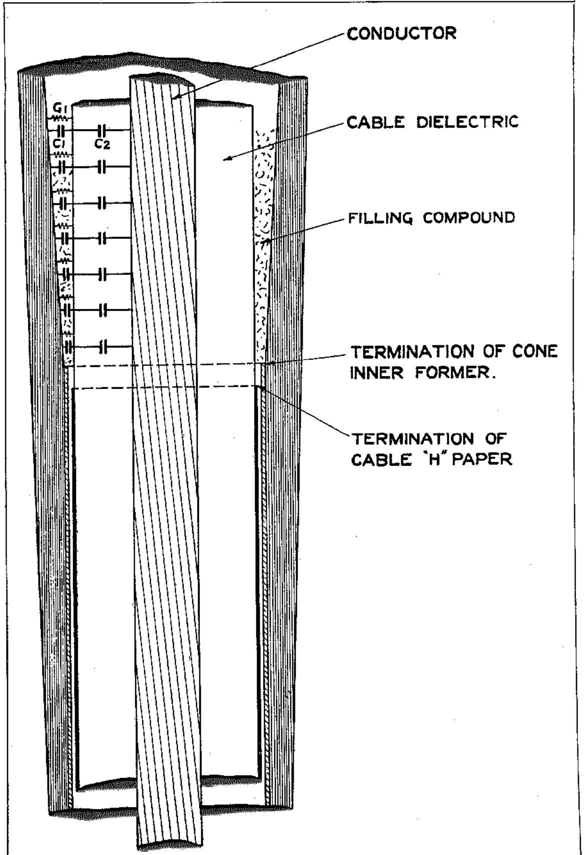

CONDUCTOR
CABLE DIELECTRIC
FILLING COMPOUND
TERMINATION OF CONE INNER FORMER.
TERMINATION OF CABLE 'H' PAPER
G1
C1
C2

Fig. 6—*Section of Base Cone on Cable End showing Capacity Interlinkages between Filling Compound and Cable Dielectric. By controlling the Value of* C_1 *and* G_1 *the Stress may be transferred to* C_2.

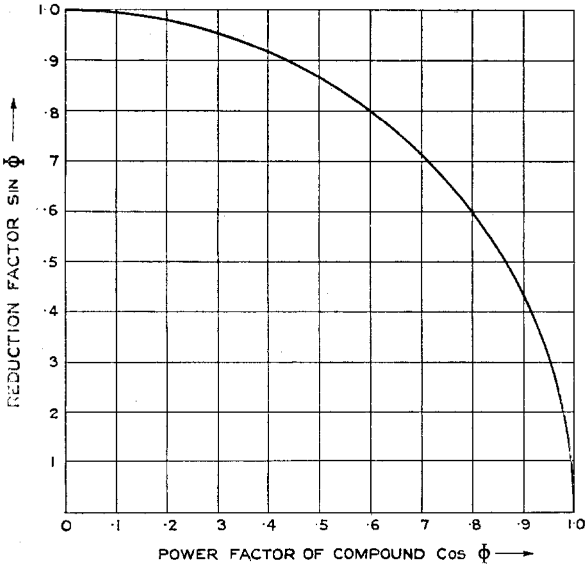


Fig. 7—*Graph showing how by increasing the Power Factor of the Filling Compound, the Radial Stress thereon is reduced.*

TABLE V

C.C.11 (Plastic Compound)

Temp. °C.	Power Factor Cos Φ at 50 p : s.
20	0.63
30	0.78
40	0.87
50	0.92
60	0.95

The permittivity is 3.8 and the *B.D.V.* is 45 kV. This compound will adhere tenaciously to oil impregnated paper, and is very effective in sealing the end of a cable on test from outside sources of contamination. To complete the seal, the inner tin tube of the cone may be soldered to the lead sheath, provided the cone is fitted over the "*H*" paper. Alternatively, it may be slipped over the lead sheath so that the compound attaches itself to the latter. These two methods are illustrated in Fig. 8.

Cones may conveniently be used as guard-rings, an application which is valuable when taking Schering-bridge readings. Ordinary guard-rings used in the open do not altogether guard against the effect of the vigorous sparking which occurs at higher voltages unless the cable is effectively screened, but cones do not suffer from this defect. The technique of adapting cones as guards is as follows :

The lead should first be trimmed from the end for a distance equivalent to the total length of the cone, and the "*H*" paper removed for a distance corresponding to the length of the inner cone. A ring of "*H*" paper about $\frac{1}{8}$ inch wide should then be removed approximately $\frac{1}{2}$ inch from the lead sheath. This ring should first be covered with an oil impregnated paper about 1 inch wide, and then with lead foil which makes contact only with the "*H*" paper above the cut. Some binding wire round this lead foil will serve the double purpose of making contact with the cone and in preventing the latter from contacting with the lead sheath. This binding wire also serves as an earth connection, while the lead sheath is connected to the bridge circuit. Rubber tape may be used for binding round the bottom of the cone and thus preventing the escape of oil but, on completion of power factor tests, if it be desired to take a long voltage run, the earth connection from the cone should be cut short and bound over with rubber tape ; otherwise oil tends to leak out where it projects.

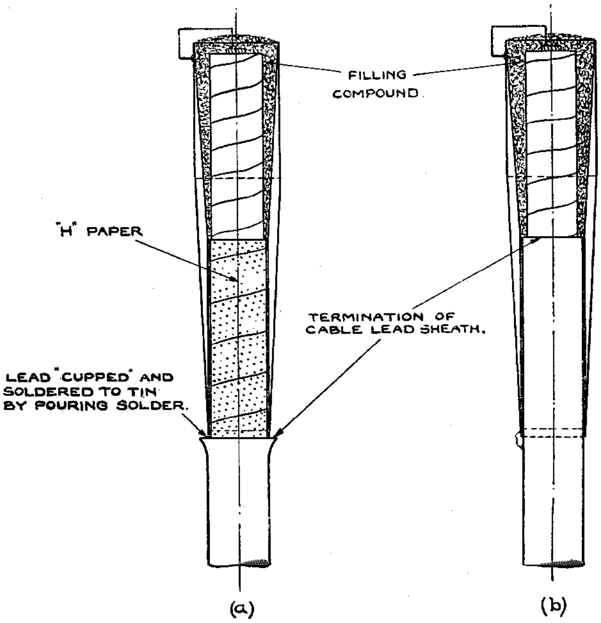

FILLING COMPOUND
"H" PAPER
TERMINATION OF CABLE LEAD SHEATH.
LEAD "CUPPED" AND SOLDERED TO TIN BY POURING SOLDER.
(a)
(b)

Fig. 8—Cones filled with Plastic Compound to seal off Cable End. Oil-impregnated Cones so filled, as in (b), have been working satisfactorily on Accelerated Ageing Tests in Air continuously for Eleven Months.

The special compounds described herein may be used for cases in which the minimum cable stress does not exceed about 11 kV/mm. Referring again to Table II, this value will be seen to correspond to voltages 6 to 8 times working voltage, depending on the type of cable. If still higher voltages are contemplated, then the cable insulation may be built up so that the calculated stress at the outer surface of the added insulation will not exceed 11 kV/mm. In this way the highest possible voltages may be achieved.

It should be noted in particular that increasing the size of the conductor has the effect of augmenting the minimum cable stress. This is clearly indicated in Table II. Thus the tests on large conductor cables are relatively more severe than on those having small conductors as far as the ends are concerned.

Voltage tests may be divided into two main categories :

(*a*) Acceptance tests.
(*b*) Breakdown tests.

Considering the two cables given in Table II, the acceptance tests as specified in various countries would be as listed in Table VI.

In the case of the British and German tests, ordinary cable oil might be used to fill the cones. There would be no necessity to build up the insulation since it will be noted that the minimum cable stress lies below the limit of 5.5 kV/mm at the test pressure. Americans, however, would either have to build up the insulation or use special compound.

Voltage tests to breakdown are not covered by British specification. The German *V.D.E.* specification calls for a 5 minute test of 6 times working voltage on 5 metre samples. This corresponds to 114 kV for 33 kV cables and 228 kV for 66 kV cables. American practice specifies tests on selected samples as given in Table VII, corresponding to voltages of 130 kV

TABLE VI

Rated Voltage kV. 3 Phase (British Rating).	British (Customary Test).		German (V.D.E. Spec.).		American (A.E.I.C. Spec.).	
	Test Voltage 1 Phase to Earth kV.	Period Minutes.	Test Voltage 1 Phase to Earth kV.	Period Minutes.	Test Voltage 1 Phase to Earth kV.	Period Minutes.
33	53	15	49	30	72	15
					86[5]	15
66	106	15	97	30	150	15
					179[5]	15

on 33 kV cables and 260 kV on 66 kV cables.

TABLE VII

As specified in normal high-voltage test	6 hours
300 volts/mil of specified insulation . .	3 hours
350 ,, ,, ,, ,, . .	3 hours
400 ,, ,, ,, ,, . .	until failure occurs.

Manufacturers for their own information might wish to make short time breakdown tests on samples of cable on even higher voltages. In all such cases, the minimum cable stress at the voltage considered should first be calculated. If this does not exceed 11 kV/mm a cone fitting directly over the cable dielectric may be used if filled with special compound. For stresses exceeding 11 kV/mm the insulation should be built up as already indicated.

Standard cones increase in diameter by increments of 0.2 inch, providing a tolerance which is permissible with respect to any cable. If it be desired to use a cone which is normally too big for a particular cable, the insulation of the latter may always be built up to suit. It has not been found necessary to centre the cable accurately in the cone.

---

[5] On 15 per cent. of lengths.

Recent Telecommunication Developments of Interest

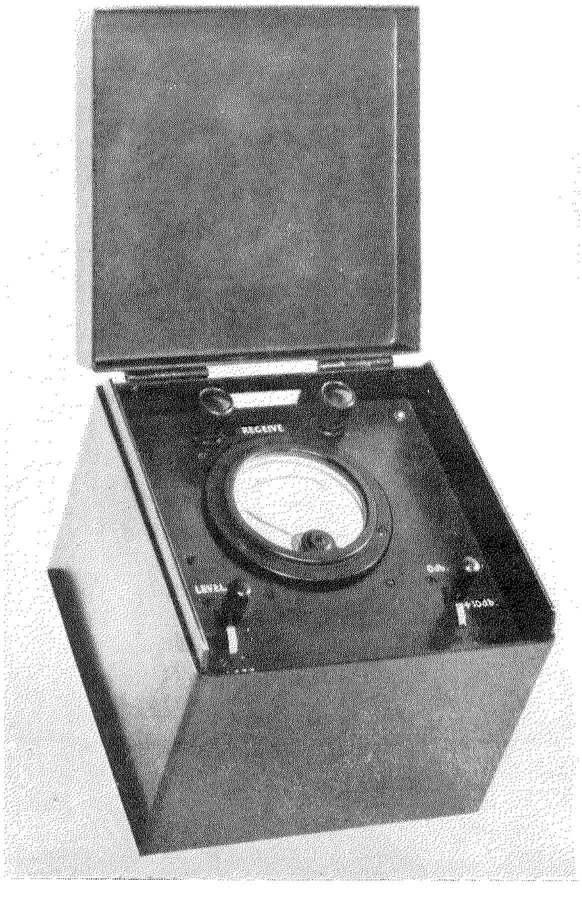
DIRECT READING TRANSMISSION MEASURING SETS of compact and simple design, giving reasonably accurate results, are recent developments of Standard Telephones and Cables, Limited, London. The sets meet the requirements for simple and lightweight testing apparatus, and are intended as auxiliaries to more precise and expensive transmission measuring sets. They should prove useful in the general maintenance of telephone systems.

Recent advances in meters and metal rectifiers are embodied in their design, and no battery or calibrating oscillator is required. Due to the high input impedance, lower levels can be measured than is usual with these types of instruments.

The 74105-A set covers the voice frequency range of 35 to 5000 p : s. The measuring range of this set is + 20 db to – 15 db (or alternatively, +2 to –1.75 nepers) with an accuracy of ± 0.5 db.

The 74105-B set covers the 50–50 000 p : s range and is suitable for measuring levels of –10 db to + 20 db (– 1.0 to + 2 nepers) referred to 1 mW in 600 ohms. The accuracy is ± 0.5 db up to 10 kc and ± 1.0 db up to 50 kc.

The Sets are mounted in robust metal boxes. The 74105-A set measures 6 × 6 × 5 in. (152 × 152 × 127 mm) and weighs 9 lb. (4 kg). The 74105-B set is somewhat smaller; it measures 6 × 3¾ × 3¼ in. (152 × 95 × 83 mm) and weighs 2½ lb.



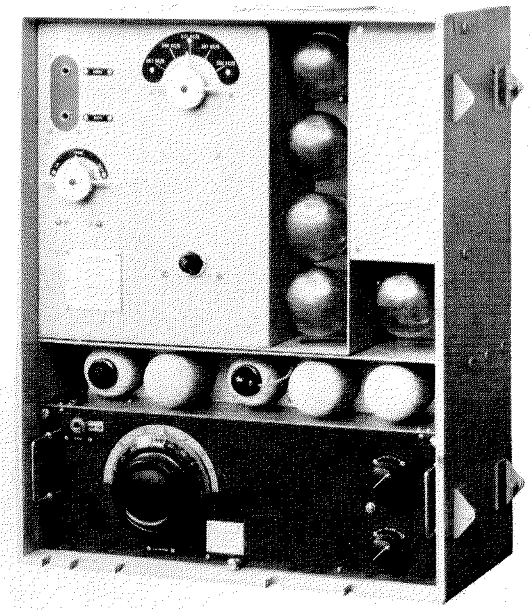
Transmission Measuring Set.

• • •

AIRCRAFT RADIO EQUIPMENT (Type R.9). The rapid growth of civil aviation during the last few years has resulted in a European network of daily scheduled air routes. It has become necessary to allocate internationally specified wavelengths to handle the increasing volume of aviation radio traffic and to confine their use to well defined zones controlled and served by established aerodrome and other radio ground stations. It is, therefore, increasingly important for the aircraft transmitter to have these international wavelengths preset, and for the pilot to be able to switch instantaneously from one wavelength to another—each change being registered by well-defined "clicks" and suitable dial indication.

The R.9 Aircraft Radio Equipment, developed by Standard Telephones and Cables, Limited, to meet these requirements, provides for radio telephone or telegraph transmission on six fixed medium wavelengths, namely: 600—827—862—900—918 and 932 metres (500—363—348—333—327 and 322 kc respectively) and for reception on wavelengths between 550 and 1150 metres (545 and 261 kc respectively).

The inclusion of 600 metres permits aircraft



Aircraft Radio Equipment.

engaged on overseas flying to communicate with any ship or shore station operating on 600 metres.

The R.9 equipment allows full advantage to be taken of navigational assistance from medium wave direction finding stations as well as of two-way communication with ground stations.

The method of installation varies according to the type of aircraft and whether the equipment is to be operated by direct or remote control. When the equipment is to be operated by the pilot only, remote control is usually used.

Where space permits, the transmitter and receiver units are mounted in a single box, as illustrated. If necessary, however, the two units can be supplied in separate cases and mounted apart, provided the receiver is kept reasonably near to the transmitter. In all cases, shock absorbing slings are provided.

The control box, being relatively small, may be located to suit the convenience of the operator. The fairlead should be installed as near as possible to the aerial winch, while the latter must be accessible to the operator.

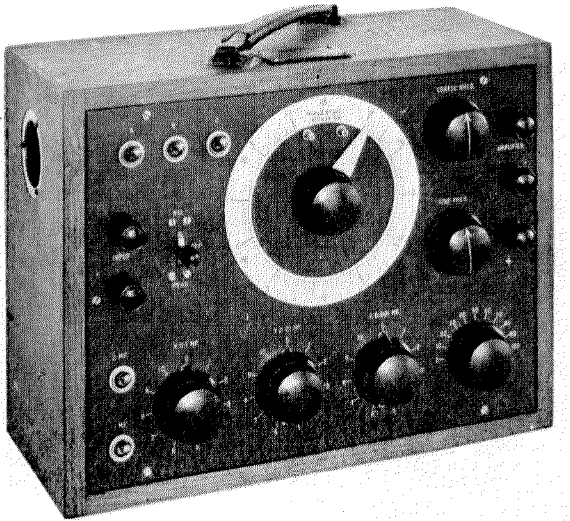
The equipment can be operated either from a wind-driven generator mounted in the leading edge of the wing or under the fuselage, or from the 12-volt plane battery. The power supply is suitably filtered.

The method of construction permits much latitude in the installation of the equipment, which can be fitted in aircraft ranging from the small Moth variety to the largest multi-engined machines.

● ● ●

A DISTORTION FACTOR METER, No. 74300-A, has been developed by Standard Telephones and Cables, Limited, London, to provide a simple method of harmonic content determination without the complexities which are inherent in high precision wave form analysis. In conjunction with a suitable amplifier, it can be employed for measuring the harmonic content of any voice frequency wave form.

This meter is intended as a general purpose harmonic measuring set for the quantitative determination of the quality of the output from oscillators or amplifiers over the voice frequency range. Fundamental frequencies from 20 to 3000 p : s and the total harmonic content (i.e., ratio of total harmonics to fundamental plus harmonics) up to 10 per cent. can be measured. The associated amplifier must have a flat frequency response over the range 20 p : s to 10,000 p : s, and the No. 74302-B amplifier is specially recommended for this purpose.



Distortion Factor Meter.

The overall dimensions of the set are 12 × 9 × 5½ in. (305 × 229 × 140 mm), and the weight is 20 lb. (9 kg).

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